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MARKET SURVEY OF PRESSURE
VESSELS FOR SYNTHETIC FUEL
PRODUCTION SYSTEMS

FINAL REPORT

By

MICROMEDIA

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EXECUTIVE SUMMARY

The Canadian demand for crude oil during the coming two decades will likely be supplied from a combination of sources - conventionally produced crude oil, upgraded heavy oil and oil products from oil sands projects. In addition, the vast Canadian coal reserves could well add to the supply base in the form of liquid products and gaseous fuels. These upgrading and conversion technologies are at early stages of their commercial development, some having not yet progressed beyond the pilot plant stage.

All of the more promising processes operate at severe conditions - pressures of 15,000 kPa (2,000 psi) and more, temperatures of 800°C (1500°F) and higher and atmospheres with hydrogen content of 1% and up. Process requirements and economics dictate the size of the primary and secondary reactor vessels which are commonly limited by the capability of fabricating plants and the logistics of transportation. While there exists some flexibility with respect to the length of these vessels, the overall diameter can seldom exceed 4.50 meters (14 feet).

Typically, the reactors are of very thick wall. Some particularly heavy examples reach wall thicknesses of up to 350 mm (about 14 inches) and total weight of over 1,000 tonnes. To date, the majority of these vessels have been produced by a few specially equipped foreign fabricators in the U.S., Japan, Germany and Italy, but none in Canada except for a select few of up to 165 mm (6½ inches) and one vessel of layered construction of 250mm (8½ inches) total wall thickness.

Energy, Mines and Resources, represented by its Physical Metallurgy Research Laboratory (PMRL), part of the Canada Centre for Mineral and Energy Technology (CANMET), have recognized the need for an evaluation of the total demand to the year 2000 for such heavy wall pressure vessels in the hydrocarbon conversion industries in order to identify potential opportunities in the field and embark on research and development programs for improving fabrication technologies and assisting industrial fabricators. To conduct such a survey and forecast, PMRL commissioned Chinook Fuel Innovations Ltd., who have experience in various aspects of heavy oil upgrading and coal conversion technologies, as well as in welding, metallurgy and market surveys and technology forecasting.

The forecast evaluated the demand for pressure vessels of 63mm (2½ inches) and thicker wall for those energy projects that were considered likely to come to fruition in the forecast period. This evaluation included consideration of the process technologies suggested by process developers and project sponsors.

Applying technology assessment principles, the likely process technologies for the next twenty years were identified and their heavy wall pressure vessel requirements for particular plant sizes determined. While a large number of those earlier forecasted energy projects will either be delayed or never come to fruition, a mix of 25 heavy oil upgrading, oil sands and coal conversion projects were assumed to come on stream by the year 2000. From this project listing, a calendar of heavy wall pressure vessel procurements was derived.

An overview evaluation of the Canadian capabilities of steelmakers and vessel fabricators was carried out as well as their respective problems of competition and opportunities and the improvement of business environment. Further identified were material requirements and technological gaps in fabrication capability and Canadian steel supply, as well as opportunities for research and development programs.

The total base case demand of about 640 heavy wall pressure vessels, when divided into wall thickness classes, are distributed as follows:

250-300mm (10-12") - 90 vessels of 500+ tonnes weight;
150-250mm (6-10") - 140 vessels of 200-500 tonnes weight;
100-150mm (4-6") - 150 vessels of below 200 tonnes weight;
63-100mm (2.5-4") - 260 vessels of below 200 tonnes weight.

This base case forecast relies on the occurrence of significant events, e.g., the Al sands Project being actually constructed (with such a decision reached in 1982) and the assumption that the world oil price would not deteriorate further than about \$32.00 (US) per barrel, but increase again in 1983. Further, the Canadian economy was assumed to be recovering throughout 1982 and 1983, subsequently reaching an acceptable growth rate.

A negative impact on the demand for heavy wall pressure vessels, could be exerted by the early development of offshore oil if 31,850 m³/d (200,000 b/d) can be produced from the Hibernia Field at the East Coast of Newfoundland by 1982, plus doubling this capacity by 1989. If coupled with a continuation of low level incentives for mainland energy projects, a

cancellation of many of the early projects and a further delay of the remaining projects would likely result in the drop of vessel demand figure to 175. Should the world oil price drop significantly below the \$30.00 (US) mark and remain at this low level for the remainder of the 1980's, the Canadian heavy wall pressure vessel market will likely be reduced to insignificance, except for a few politically motivated pilot projects in primarily economically depressed areas of the country.

An optimistic scenario though could be achieved if governments of all levels were to increase the incentives for relevant projects significantly; if offshore and Beaufort oil production would be delayed into the 1990's decade; and, if the world oil price increases soon and strongly (not later than 1983), then the pressure vessel market from Canadian energy projects could rise to a total of about 860 vessels.

Given such scenarios, the Canadian steelmakers are not likely to invest to the level required to produce such standard heavy pressure vessel materials as 2½ Cr-1Mo. Whereas the Canadian fabrication industry will be capable of producing the majority of the forecasted vessels of up to 200mm (8 inch) wall thickness with little investment required to update equipment, fabricating procedures and human skills. Although not more than half a dozen of the fabricators are aggressively marketing their skills and facilities, these will likely produce the vast majority of the Canadian supply. This assumes, however, that fiscal competitiveness with foreign suppliers, particularly Japanese, is instituted through domestic financing programs.

The opportunities for Canadian industry as a whole lie in vessel thicknesses of up to 200mm (8 inches) wall thickness, which could include the supply of domestic steel if vessels were to be fabricated from thin layers. It is likely that the majority of heavy wall pressure vessels will be of the hydrogenation reactor type for such refinery feedstocks as gas oil, distillate and naphtha, representing almost 50% of the vessel demand.

Concerted efforts in establishing fabrication procedures for lower alloy steels suitable for the severe operating environment of these vessels, including welding and post weld heat treatment, would provide the more aggressive Canadian fabricators with a position to be technologically competitive.



INDEX

EXECUTIVE SUMMARY	i
INDEX	iv
LIST OF TABLES	viii
LIST OF FIGURES	ix
ACKNOWLEDGEMENTS	x
1. INTRODUCTION	1
2. TERMS OF CONTRACT	5
3. CONCLUSIONS	7
4. RECOMMENDATIONS	12
5. SURVEY METHODOLOGY	16
6. DEFINITION OF PRESSURE VESSELS	20
6.1 CODES AND STANDARDS	20
6.1.1 THE APPLICABILITY OF THE ASME CODES	20
6.1.2 ANALYSIS OF ASME CODE, SECTION VIII, DIVISIONS 1 AND 2	23
6.1.3 REPRESENTATIVE INTERNATIONAL CODES	25
6.2 REPRESENTATIVE OPERATING CONDITIONS	26
6.3 BASIC CONSTRUCTION PRINCIPLES	27
6.4 COMMON MATERIALS IN CONSTRUCTION	30
6.5 TYPICAL CURRENT FABRICATION TECHNIQUES, INSPECTION AND SAFETY	37
6.5.1 FABRICATION - SHOP	37
6.5.2 PREHEATING	38
6.5.3 POSTWELD HEAT TREATMENT	39
6.5.4 FABRICATION - FIELD	39
6.5.5 NON-DESTRUCTIVE TESTING (NDT)	41
6.6 CRITICAL ISSUES FOR THICK WALL PRESSURE VESSELS IN TYPICAL ENERGY CONVERSION SYSTEMS	44
6.7 DEFINITION FOR THE PURPOSE OF MARKET SURVEY FORECAST	49

7.	SYNTHETIC FUEL PRODUCTION SYSTEMS	50
8.	SYNTHETIC FUEL PROCESSES EMPLOYING THICK WALL PRESSURE VESSELS	53
8.1	HEAVY CRUDE UPGRADING	53
8.2	COAL LIQUEFACTION	59
8.2.1	GENERAL	59
8.2.2	CATALYTIC HYDROGENATION	62
8.2.3	SOLVENT EXTRACTION	64
8.2.4	PYROLYSIS OR HYDROCARBONIZATION	65
8.2.5	INDIRECT LIQUEFACTION	67
8.3	SECONDARY UPGRADING/HYDROTREATING	69
8.4	COAL GASIFICATION	73
8.5	METHANOL AND AMMONIA SYNTHESIS	75
8.5.1	METHANOL SYNTHESIS	75
8.5.2	AMMONIA SYNTHESIS	78
8.6	PROCESS EVALUATION AND FORECAST OF TECHNOLOGY	83
9.	OUTLOOK ON CANADIAN ENERGY PROJECTS	91
9.1	ENERGY PROJECTS ANNOUNCED	91
9.2	CANADIAN ENERGY DEMAND FORECAST	94
9.3	RELEVANT GOVERNMENT POLICIES	101
9.3.1	FEDERAL	101
9.3.1.1	THE NATIONAL ENERGY PROGRAM	101
9.3.1.2	THE OFFSHORE INCENTIVE PROGRAM	103
9.3.1.3	THE OTTAWA/ALBERTA ENERGY PRICING AGREEMENT	104
9.3.2	PROVINCIAL	105
9.4	INFLUENCE ON CANADIAN ENERGY PROJECTS BY WORLD OIL PRICE DEVELOPMENTS	106
9.5	INDUSTRY VIEW OF DEMAND UNDER RECENT DEVELOPMENTS	111
10.	FORECAST OF INTERNATIONAL PROJECTS	113
10.1	UNITED STATES OF AMERICA	113
10.2	JAPAN	119

10.3	EUROPE	120
11.	DEMAND ANALYSIS FOR THICK WALL PRESSURE VESSELS IN CANADA	122
11.1	LIKELY CANADIAN ENERGY PROJECTS	122
11.2	HEAVY WALL PRESSURE VESSEL DEMAND FOR TYPICAL PROJECTS	133
11.2.1	GENERAL	133
11.2.2	OIL SANDS	133
11.2.3	HEAVY OIL UGRADING	134
11.2.4	COAL LIQUEFACTION	134
11.2.4.1	DIRECT COAL LIQUEFACTION BY HYDROGENATION	134
11.2.4.2	INDIRECT COAL LIQUEFAC TION BY FISCHER-TROPSCH	135
11.2.5	CARBON DIOXIDE (AND HYDROGEN) FOR ENHANCED OIL RECOVERY AND UP- GRADING	135
11.2.6	METHANOL AND AMMONIA SYNTHESIS	136
11.3	BASE CASE OF DEMAND FORECAST	136
11.4	OPTIMISTIC AND PESSIMISTIC CASES	139
12.	CANADIAN SUPPLY CAPABILITY NOW AND IN THE FUTURE	141
12.1	STEEL MAKING AND MATERIAL PROPERTIES	141
12.1.1	CURRENT STEELMAKING CAPABILITY	141
12.1.2	FUTURE STEEL MATERIALS REQUIRE- MENTS	142
12.1.3	CONCRETE AS FUTURE COMPETITOR OF STEEL	143
12.1.4	"MEGACOON" PRESSURE VESSEL CONCEPT	154
12.1.5	FUTURE CANADIAN STEELMAKING CAPABILITY	156
12.2	FABRICATION	157
12.2.1	CURRENT FABRICATION CAPABILITY	157
12.2.2	FUTURE PRESSURE VESSEL DESIGNS	159
12.2.2.1	GENERAL	159
12.2.2.2	REACTOR DESIGN CRITERIA AND SELECTION	160

12.2.3	FUTURE TESTING REQUIREMENTS . . .	168
12.2.4	FUTURE FABRICATION TECHNIQUES . . .	169
12.2.5	FUTURE CANADIAN FABRICATION CAPABILITY	172
12.3	ANTICIPATED COST OF HEAVY WALL PRESSURE VESSELS	175
12.4	FUTURE CRITICAL ISSUES	179
13.	INDUSTRIAL BENEFITS TO CANADA	180
14.	TECHNOLOGICAL GAPS	182
	REFERENCES	185

APPENDICES

- A - WORLDWIDE PRESSURE VESSEL CODES
- B - CARBON REJECTION PROCESSES
- C - HYDROGEN ADDITION PROCESSES
- D - COAL LIQUEFACTION PROCESSES
- E - COAL GASIFICATION PROCESSES
- F - DETAILED INVENTORY OF MAJOR CANADIAN PROJECTS
TO THE YEAR 2000
- G - DESCRIPTION OF FORECASTED PROJECTS

LIST OF TABLES

8-1	COMPARISON OF VARIOUS CRUDE COMPOSITIONS AND PROPERTIES	54
8-2	TYPICAL DATA FOR ICI QUENCH CONVERTERS OF VARIOUS SIZES	81
8-3	TYPICAL DATA FOR ICI QUENCH CONVERTER OF 1,300 STD CAPACITY	81
8-4	SYNTHETIC FUEL PRODUCTION SYSTEMS	84
8-5	PROCESS TECHNOLOGY FORECAST	90
9-1	HYDROCARBON/FOSSIL CONVERSION RELATED PROJECTS	92
9-2	PROPOSED MEGAPROJECTS TO 2000 AD	93
9-3	INDUSTRY RESPONSE TO NEP	95
11-1	PROJECT CALENDAR	126
11-2	THICK WALL PRESSURE VESSELS FOR TYPICAL ENERGY PROJECTS	137
11-3	FORECAST OF PRESSURE VESSEL ORDERS	138
12-1	INTERNATIONAL FABRICATORS OF HEAVY PRESSURE VESSELS	174
12-2	OVERVIEW OF TYPICAL EQUIPMENT REQUIREMENTS AND COST FOR A PLANNED U.S. COAL LIQUEFACTION PROJECT	177

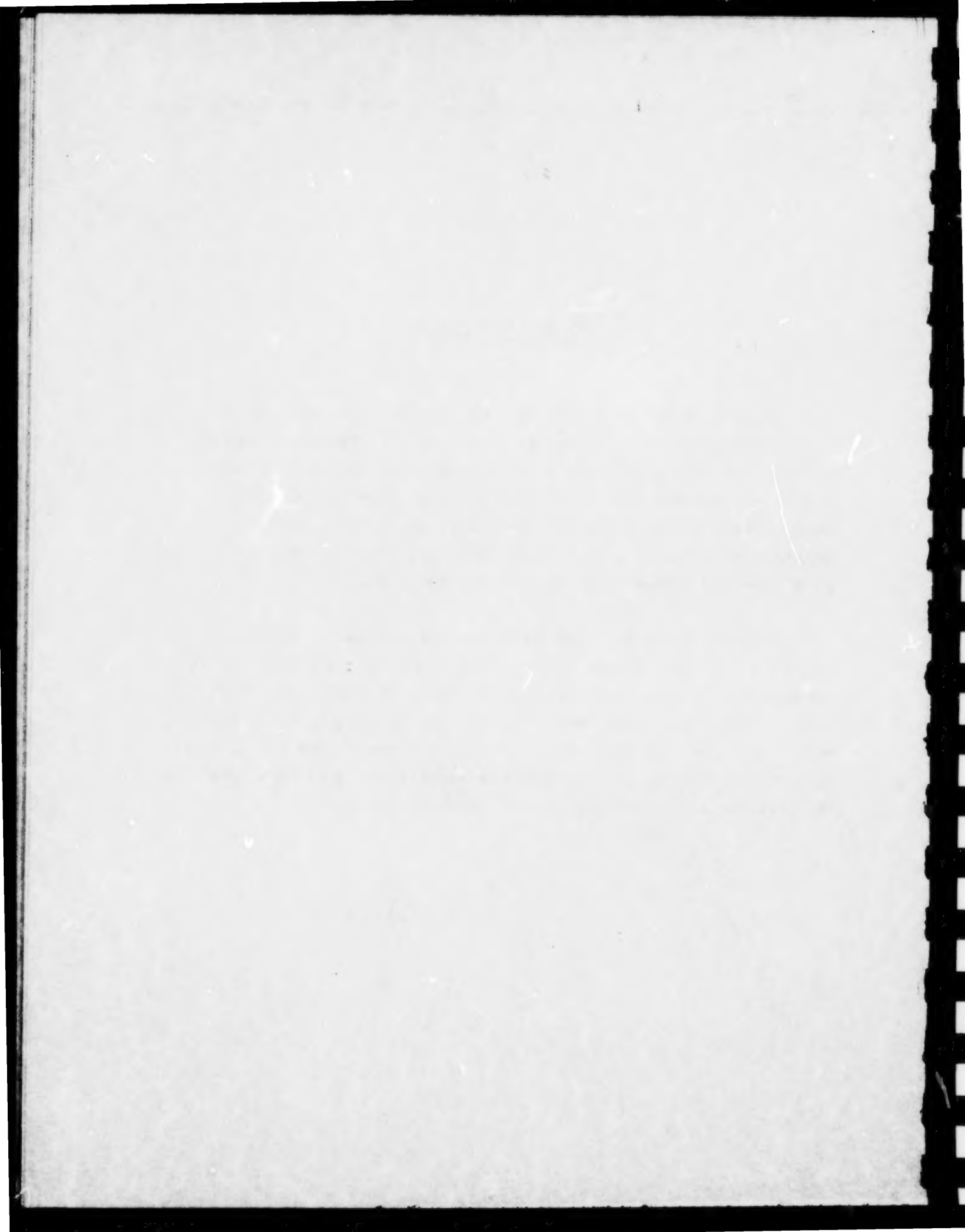
LIST OF FIGURES

8-1	PROCESS SEQUENCE FOR UPGRADING	56
8-2	TYPICAL HYDROTREATER	70
8-3	LURGI BOILING WATER LOW-PRESSURE METHANOL REACTOR FOR 2,500 STPD PLANT	77
8-4	FLOWSHEET FOR AMMONIA SYNTHESIS	79
8-5	ICI QUENCH-TYPE CONVERTER	80
9-1	SUPPLY & DEMAND - CRUDE OIL AND EQUIVALENT BASE AND MODIFIED BASE SUPPLY WITH MIDDLE DEMAND	97
9-2	FORECAST OF CONVENTIONAL CRUDE OIL SUPPLY AND OF TOTAL OIL DEMAND	99
11-1	CAPACITY INCREASE HEAVY OIL UPGRADER	127
11-2	CAPACITY INCREASE OIL SANDS - SURFACE	128
11-3	CAPACITY INCREASE OIL SANDS - IN-SITU	129
11-4	CAPACITY INCREASE COAL LIQUEFACTION	130
11-5	PRODUCTION OF CRUDE OIL OR EQUIVALENT	132
12-1	EFFECT OF TEMPERATURE ON STRENGTH OF CONCRETE . . .	145
12-2	A MODEL OF THE 'PODDED BOILER' STYLE PRESSURE VESSEL WITH THE WIRE WINDING PRESTRESSING MACHINE	149
12-3	COAL CONVERSION PRESTRESSED CONCRETE MULTI-CELL PRESSURE VESSEL	153
12-4	A SCHEMATIC ILLUSTRATION OF A COMPOSITE PRESSURE VESSEL WITH COMPUTER CONTROLLED ACTIVE HEAT SHIELDS	155

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1. INTRODUCTION

Recognizing the growing significance of alternative oil production to supplement dropping conventional oil production in Canada, CANMET of Energy, Mines and Resources Canada, through its Physical Metallurgy Research Laboratory, has committed itself to an extensive program to study and further develop the technologies as they relate to the manufacturing of very heavy wall pressure vessels required in many processes of alternative crude oil production. This ongoing pressure vessel program of CANMET, considers the material properties of steels, the techniques to fabricate the pressure vessels, including welding and heat treatment, as well as the quality control and inspection methods.

Many of the alternative crude oil processes will operate at pressures of up to 17,000 kPa (2,500 psig) and temperatures of up to 1500°C (2800°F) in extreme corrosive, erosive and high hydrogen content environments. Many of the process streams contain large quantities of highly abrasive solids including silicas, clays and other mineral contents. Because of severely changing the chemistry of heavy oils, refinery resids or coals with or without catalysts, some process based residence time requirements increase the vessel heights to 60 m (200 feet) and to internal diameters of 3.6 m (about 12 feet) which relates to wall thicknesses of up to 300 mm (12 inches).

To date, few vessels were required as part of the relevant processes or working under such extreme operating conditions. However, the large number of announced or planned energy projects in Canada suggest rapidly growing demand for this type of vessel. Satisfying this demand represents a major challenge to the Canadian industry including the following capabilities:

- steel making of optimum type and grade;
- rolling, forming of thick plate;
- welding of thick plate;
- quality control;
- non-destructive testing.

CANMET have made it an obligation to investigate all aspects of requirements for such a capability and advise Canadian industry on the opportunities and technologies required for development. Their project Pressure Vessels identifies two main objectives:

- to develop and evaluate fabrication and inspection technologies; and,
- to evaluate in-service performance of pressure vessel materials.

To date, the few pressure vessels of relevant extreme size and material were provided by overseas countries, mainly Japan and Europe.

While this survey and forecast is to provide quantitative information on the current Canadian capability and the requirements of industry's needs to meet future demand, it is also to estimate the overall

pressure vessel demand for the next two decades by identifying those projects likely to be built.

This report then is structured to lead from the definition of pressure vessels (for the purpose of this review), to provide an overview of the alternative crude oil production methods, including the descriptions and evaluations of the most promising processes; to include estimates of typical numbers and types of pressure vessels per process and per typical project; to identify the total pressure vessel demand to the year 2000, including technical barriers having an effect on the total demand; to report the Canadian demand in relation to international situations, as well as identify potential export opportunities for the Canadian industry; relevant international projects are forecast as well to establish a demand base case comprising optimistic and pessimistic scenarios; to identify the Canadian supply capability and needs in meeting the demand.

In detail, Section 2 describes the terms of contract, while Sections 3 and 4 contain findings and recommendations for future work, respectively. The methodology used to carry out this survey/forecast is identified in Section 5. Section 6 is the definition of pressure vessels, including codes, common materials, construction principles and fabrication techniques as well as critical current issues. Following this is a Section that describes the various options of hydrocarbon based energy conversion systems as alternatives to the production of conventional light crude oil, and as these options relate to heavy wall pressure vessels. Section 8 identifies the various pro-

cesses including technology forecast and forecast of material properties, fabrication technologies and competing materials and fabrication techniques.

A discussion of Canadian energy projects is given in Section 9, beginning with the announced energy projects and the relevant government policies; reference is made to the world oil price developments in the current views by industry leaders on the situation to date and the outlook into the future. Section 10 identifies relevant international project forecasts for the U.S., Japan, Europe and other countries.

The detailed demand analysis for thick wall pressure vessels is then executed in Section 11, including the forecast of the Canadian energy projects likely to proceed and the number of vessels on a project-by-project basis, to arrive at the base case forecast and the optimistic and pessimistic cases. In Section 12, the Canadian current and future capability in steelmaking, fabrication, certification and quality controls are described. Industrial benefits to Canada are identified in Section 13, while the technological gaps requiring attention in order to meet the demands are described in Section 14.

Finally, appendices are included to provide further background information relating to this project.

2. TERMS OF CONTRACT

TITLE: MARKET SURVEY OF PRESSURE VESSEL REQUIREMENTS
FOR SYNTHETIC FUEL PRODUCTION SYSTEMS

REQUIREMENT: On behalf of CANMET/EMR, to provide a Canadian market assessment of the pressure vessels required for energy conversion processes including tar sands and heavy oil upgrading, coal liquefaction and gasification.

WORK STATEMENT

1. The number, size, material specifications and operational conditions of pressure vessels will be determined for all present state of the art energy conversion processes. A minimum of two scenarios will be postulated to reflect a low and high level of activity for synfuel production and fossil fuel utilization to the year 2000.
2. The survey of these requirements will include reference to conventional and developing fabrication technologies for lining vessels; non-destructive testing; and certification standards.
3. Estimates of vessel costs (1981\$) will be provided.
4. The detailed market forecast for Canada will be supplemented by a more general level of forecast for other countries, viz the U.S., Japan and

E.E.C. countries, to permit Canadian projections to be viewed in an international perspective.

5. A survey of current and projected Canadian capability to supply and fabricate the variety of pressure vessels identified in items 1 and 2. The Canadian supply potential will be contrasted with that of other countries active in the pressure vessel market.
6. The data generated under 1-5 will be analyzed and presented in such a manner as to facilitate identification of the potential industrial benefit to Canada of synthetic fuel production projects; and to facilitate identification of gaps in present Canadian technology which may impede the realization of such industrial benefit.

3. CONCLUSIONS

Based on many personal interviews which included detailed discussions on the major issues of the industry, we concluded that the Canadian pressure vessel fabricators are highly competitive with high quality products.

While the public perception of the low state of the energy projects may be tainted by the current dismal affairs of the country's economy and the events surrounding the Alsands and other relevant projects, the outlook for the demand of heavy wall pressure vessels is quite strong.

Over the forecasting period, a total of 640 vessels will be procured (base case demand). These are only vessels that operate under severe conditions:

- 7000 kPa (1000 psig) pressure and higher;
- 800°C (1500°F) temperature and more;
- 1% by weight (10,000 ppm) and over of hydrogen;
- wall thickness of 63 mm (2½ inches) and up.

All of the many pressure vessels not fitting these constraints were excluded from the survey/forecast. Further excluded, were heat exchangers, boilers and other similar equipment.

In detail, the following findings can be reported:

- i) A high degree of uncertainty currently surrounds the planned energy projects. Project sponsors

are reluctant to predict project go-ahead or timing for the following reasons:

- domestic and international low state of the economy;
- world oil price deterioration;
- insufficient tax incentives.

ii) There is no measurable market in the year 1982.

iii) We see the world oil price increasing well within this decade and a Canadian energy scenario evolving which is conducive to the development of many of the announced projects, though delayed by years.

iv) The demand for heavy pressure vessels is fairly evenly distributed:

- 76 for 1983 to 1985;
- 140 for 1986 to 1990;
- 262 for 1991 to 1995; and,
- 163 for 1996 to 2000.

v) These vessels fall into wall thickness and weight ranges of:

- 90 of 250-300mm (10-12") wall and 500 tonnes plus;
- 140 of 150-250mm (6-10") wall and 200-500 tonnes;
- 150 of 100-150mm (4-6") wall and <200 tonnes;
- 260 of 63-100mm (2.5-4") wall and <200 tonnes.

vi) Canadian pressure vessel fabricators can be competitive in their area of marketing with vessels up to 150mm (6") wall thickness, although little appreciated by potential customers. Vessels of thicker

walls are currently almost exclusively supplied by foreign manufacturers.

- vii) The Canadian fabricators face a severe financial disadvantage because foreign competitors, particularly Japanese, receive strong export financing assistance from their governments.
- viii) Pressure vessels of up to 200mm (8") wall thickness and low alloy materials could be produced in Canada requiring some improvements of equipment, human skills and fabrication techniques. Investment required to fabricate thicker wall and alloy material would reach up to \$100 million.
- ix) For the pressure vessels investigated, little, if any, steel is supplied by the domestic steel-makers. There is also no expectation for them to supply the future thick plates over 100mm (over 4") low alloy steel market.
- x) The demand of pressure vessels may fall to 175 (low case) if the world oil price continues to drop to a level that renders Canadian energy projects uneconomic, and remain there until 1990. For an optimistic case, the demand could increase to possibly 860 vessels given an early and strong increase in the world oil price and in the incentives for investment by Canadian governments.
- xi) Canadian fabricators continually face the argument by potential vessel users that they lack experience in thick wall vessel fabrication. This "being given a chance" represents one of the more significant problems of the industry.

In summary then, to bring into Canada a significantly larger share of the forecast Canadian heavy wall pressure vessels compared to what the industry achieves today, it will have to demonstrate to the Canadian buyers that it is:

- economically competitive;
- capable of producing high quality products, even if it lacks some experience;
- prepared to provide better after-sales services than the competition;
- willing to establish innovative marketing programs.

Without assistance in the technological and fiscal areas, however, even the most progressive Canadian fabricators will continue to struggle.

Of the identified heavy wall pressure vessel demand, all but those of the range 250 mm (10") and thicker, are within the range of the Canadian fabricators. It will be necessary though that the governments sponsor research and development programs for the development of:

- state-of-the-art welding and procedures;
- appropriate testing techniques;
- most modern quality assurance procedures;
- optimized shop operations; and,
- training programs for shop floor personnel.

Financially, a very low interest rate-based short-term loan arrangement is needed by the industry. This would bring it closer to some foreign competitors whose governments provide

export financing assistance of short term interest rates of below 10%.

Canadians still would have to purchase foreign-made steel plate and compete against the lower labour rates prevailing overseas.

4. RECOMMENDATIONS

The findings suggest that there is a good opportunity for the Canadian fabricators of heavy pressure vessels to progress to the heavier wall vessels.

In addition to some technological improvements which need to be made, an environment of financial equality (with the international competition) must be instituted by the government:

- to provide financial assistance for the domestic projects similar to the EDC type programs; and,
- in order to give Canadian fabricators the chance to do it "first time", the Canadian government should provide project sponsors with a relevant incentive.

Technologically, a series of evaluations should be carried out to identify the optimum fabrication routes in a Canadian context, followed by the improvement and development of fabrication processes (including welding) and procedures.

In detail the following recommended work, when carried out, should permit the Canadian pressure vessel fabrication industry to produce competitively (in a technical sense), high quality equipment:

- 1) evaluation of the most effective vessel construction in the Canadian context considering:

- . steel sourcing and cost;
 - . transportation (location of fabrication facilities and installation sites);
 - . chemical processes;
 - . current limitations regarding thin/medium thickness fabrication equipment/capability/ know-how;
 - . potential regional concentration of energy projects;
 - . all current and developing fabrication technologies, their costs, limitations and opportunities, including importation of prefabricated parts (e.g., forgings), layered construction and others.
- ii) suggestion of amendments to the ASME Code, Section VIII, Division 2 to cover all relevant aspects of vessel construction including material properties under either Division 1 or 2;
- iii) completion of development of the following welding processes for heavy sections:
- . narrow gap;
 - . electron beam;
 - . plasma arc.
- iv) development of automatic field weld systems and heat treatment system for the field installation of very large and thick wall vessels which are transported in prefabricated sections to the project site;
- v) preparation of welding procedures for very thick

sections of low alloy steel such as 2½ Cr-1 Mo and similar (in planning);

- vi) evaluation of the market potential for clad plate, thin or thick, for application in any industry in Canada to assist the steelmakers in product planning.
- vii) extensive metallurgy research and development program including:
 - . extent of possible degradation of 2½ Cr-1 Mo and similar steels during long term service;
 - . complete understanding of stress - corrosion cracking for alloy steels;
 - . complete understanding of high temperature sulphidation, low temperature hydrogen degradation and others;
 - . determination of toughness, fracture toughness and creep and stress-rupture requirements for typical vessel operation.
- viii) for fabrication and testing techniques, procedures should be developed for layered construction, for through-thickness quality monitoring and for non-destructive testing (appropriate for thicker wall and narrow gap welding);
- ix) for insulation or linings, development programs should be conducted to include:
 - . spray-on concrete type refractory for field application;
 - . refractories sufficiently tough to survive transportation from shop to field;

- . designs for penetrations.
- x) for operations, developments should be carried out, including:
 - . understanding of failure mechanism dependent on service environment through a simulated numerical failure analysis;
 - . process related distribution/behaviour of thermal loading;
 - . extent of possible thermal excursion on basis of state-of-the-art instrumentation/control system;
 - . response of materials to coal liquefaction environment as compared to heavy oil environment;
 - . in-service vessel integrity monitoring.

5. SURVEY METHODOLOGY

The project assignment consisted of several functionally different investigations:

- i) survey;
- ii) forecast;
- iii) technology assessment;
- iv) technology forecasting;
- v) evaluation of economic environment (as it relates to energy projects current and future); and,
- vi) forecasting of economic trends.

The methodology used to conduct this survey and forecast has been optimized to achieve a high degree of transparency in forecasting to permit the reader the adaptation of the forecast over time to the actual developments.

To evaluate the current capability and the desire to expand and upgrade the Canadian industry relevant to the supply of heavy pressure vessels, discussions were conducted with the major steel manufacturers and a large percentage of vessel fabricators. As part of the evaluation, an attempt was made to identify the potential for gradual expanding of required capabilities rather than expecting this as a step function. The major elements of fabricating heavy wall pressure vessels were investigated including the production of thick steel plate of mostly light alloy steel of well controlled material properties and quality, the capability of rolling, forming or pressing of thick plate, the welding of the formed sections as well as non-destructive

testing and quality control techniques. A further attempt was made to gain relative impressions on the reputation a fabricator would have with respect to quality, innovative fabrication solutions and the marketing skill to introduce a specific capability. These discussions included the steel makers' and vessel fabricator's views on the current and future market situation, as well as attempts to identify potential future material properties favourable for the fabrication of very heavy wall pressure vessels. Identification of investment requirements, facility expansion requirements, benefits to the industry with respect to personnel and socio-economic effects were also discussed.

For the demand side of pressure vessels between now and the year 2000, the approach of the evaluation included the consideration of the great current uncertainty of economic conditions. Beginning with the listing of announced relevant energy projects - which almost completely are outdated today compared with summer, 1981 - a very critical look was taken at all of these projects and their relative merits within the context of forecasted crude oil demand and supply situations in Canada. Based on such forecasts of crude oil demand, and considering the incentive scenario for energy production as described under the National Energy Program and subsequent events, curves of supply of crude oil equivalent by the alternatives to conventional light crude oil production were derived. Using this demand situation for each of the alternatives and the like-

likelihood of some of the projects proceeding at a given time, a project calendar was derived to identify the capacity increase of crude oil equivalent over the years for each of the oil production alternatives.

For each of the typical projects of the major alternatives, the number, type and size of relevant pressure vessels as defined for this particular work, were identified with the previously derived information on number of projects so that the entire demand for pressure vessels was identified.

Considering the current economic uncertainty and the uncertainty of the future rate of natural gas as an industrial feedstock, forecast sensitivities were developed and expressed in various forms, such as, for example, the timing of a forced switch from natural gas to coal feedstocks for the "high demand" case. The "low demand" case was considered as a continuation of the current low in activities in relevant energy projects due to a downward trend of oil demand in the future, supported by oversupply of international crude oil and decreasing world market prices.

When evaluating the likelihood of announced projects becoming reality, a careful weighing included judgement by observation, discussions with operators' personnel/executives and engineers. Further, this procedure included the evaluation of the objectives of the Federal Government's initiatives on which the National Energy Program of 1980 was based, particularly with respect to

the very significant shift of interest from mainland oil and gas exploration acreage to offshore.

When discussing the pressure vessel situation with fabricators and steelmakers, their judgement of the market was discussed, plus their competition - domestic and international - as well as taxation and import restrictions. Specific attention was paid to the current technical and economic competitive edge of particularly Japanese manufacturers and what requirements would need to be fulfilled for Canadian industry to successfully counter.

Finally, the discussions included the review of development or research and development requirements to put Canadian steelmakers and vessel fabricators into a technical competitive position that would inspire Canadian customers to "buy Canadian", rather than purchase offshore.

For the evaluation of current and future practices and requirements of materials properties and fabrication techniques, data were acquired and generated through computer-based literature search, from in-house files and by interviewing of technical personnel of steelmakers, fabricators, conversion process developers and users. It is to be noted that classical forecasting techniques were not used for their lack of sensitivity to the specific mix of economical, technical, political and other constraints on the subject.

6. DEFINITION OF PRESSURE VESSELS

6.1 CODES AND STANDARDS

6.1.1 THE APPLICABILITY OF THE ASME CODES

Present Codes and Standards governing and available to the pressure vessel industry will have to be accepted as a basis for the design and fabrication for the new generation of energy conversion process pressure vessels if the market is to proceed on a timely basis. The ASME Boiler and Pressure Vessel Code was developed about 1914 and has been updated every three years since 1941. Such updating reflects the changes in materials, design considerations, fabrication and inspection techniques, operating environments, new technological requirements and safety policies. The logical development of codes and standards for the design and construction of large heavy walled pressure vessels for energy conversion systems would therefore be developed from the ASME Boiler and Pressure Vessel Code supported by the various industry standards that would be applicable.

It is apparent, however, that extensive considerations would have to be given to the design, fabrication, inspection, environmental concerns and safety elements before many thick walled pressure vessels for energy conversion processes would be built. Practical solutions to the above mentioned items would be best obtained through the traditional forum of industry-codes-standards-government regulations interactions.

Codes and standards are designed and implemented to provide the best assurance of product reliability and integrity. The very low failure rate of pressurized plants can be associated with the careful materials selection, the application of sound fabrication processes and procedures and the accurate compliance with established guidelines. To establish a quality assurance level and degree of reliability for thick wall pressure vessels, the need for an ad hoc code is given.

The following ASME Boiler and Pressure Vessel Codes are applicable:

- i) Section II - Materials Specifications
 - Part A - Ferrous Materials
 - Part C - Welding Rods, Electrodes and Filler Metals
- ii) Section V - Non-destructive Examination
- iii) Section VIII-Pressure Vessels
 - Division 1
 - Division 2 - Alternative Rules
- iv) Section IX - Welding and Brazing Qualifications.

The Code is intended to provide minimum requirements for the safe operation of pressure vessels. The ASME Boiler and Pressure Vessel Code has been adopted as a legal requirement in most states of the United States and in all of the Canadian provinces.

Although various jurisdictions have adopted the ASME Code, they have not defined the applicability of

Division 1 versus Division 2. This decision rests with the owner. The ultimate reliability and safety of plants relies upon the integrity and sound engineering judgement of the user and its construction contractors in the application of Code rules where the design application and/or jurisdiction has not legally been defined or required.

6.1.2 ANALYSIS OF ASME CODE, SECTION VIII, DIVISIONS
1 AND 2

Division 2 has been introduced to provide a more economic approach to very large and heavy pressure vessels by using a more sophisticated design calculation approach and subsequently, a reduction of the safety factor from 4 (as in Division 1) to 3. However, Division 2 does not presently adequately address vessels larger than 1,000 tonnes with wall thickness of 300 mm or greater. (ASME VIII, Div. 1, Div. 2).

For vessels exposed to very high temperatures of 425°C and up, a carefully thought out approach using data of both Divisions may be taken. Division 2 presently provides no basis for establishing an allowable design stress with creep or stress rupture properties. If the design temperature of a conversion vessel is above 480°C, the strength of a 2½ Cr-1 Mo steel changes from tensile dependent at 454°C to creep, or is stress rupture dependent at 480°C. Consequently, the allowable design stress of 17 ksi at 400°C for Class 2 material is based upon the ultimate tensile strength. One could judge that using this design stress would involve an unacceptable risk in a plant of say 20-year operational life of a reactor vessel, especially in view of the lack of creep and stress rupture test data for very heavy steel plate to define the time dependent strength behaviour at 480°C. W. Erwin et al (1982), hold that Division 2 does not

permit 2½ Cr-1 Mo at temperatures above 454°C. A similar position is taken by C.D. Lundin et al (1982).

Division 1 does contain a basis for establishing a design stress with creep, or stress rupture properties. According to the criteria in Appendix P (of the Code), the ultimate tensile strength is superceded at 480°C. However, the allowable design stress for Class 2 material is computed from stress rupture data obtained mostly from relatively thin gauge plate having strengths higher than is likely to be achieved for 300 mm thick plate. Relatively good correlations have been obtained between the room temperature ultimate tensile strengths and the stress rupture strengths. Extrapolations of these correlations indicate that an ultimate tensile strength of at least 80 ksi is necessary to guarantee exceeding the 15.8 ksi allowable design stress criterion at 480°C. The minimum tensile strengths for ASTM/A387, Grade 22, Class 2 material specified is 75.0 ksi. One could further assume that it is unlikely that ultimate tensile strengths above 80 ksi will be obtained for 300 mm thick steel plate with heat treatments representative of a fabricated vessel with a post weld stress relief required by the Code. Therefore, it may be decided to use the allowable design stress for Class 1 material at 480°C which is 13 ksi, but specify Class 2 material because of its superior toughness.

6.1.3 REPRESENTATIVE INTERNATIONAL CODES

It may occur that one and the same pressure vessel is specified, designed, fabricated and installed in different countries. While most codes are similar in philosophy of design, deviations are significant enough to warrant comparison of details if codes other than the ASME Codes are involved.

In a Special Report on Worldwide Pressure Vessel Codes, the magazine - Hydrocarbon Processing - identified in its December, 1978 issue, eight codes in addition to the ASME Code - British, German, Dutch, Swedish, Italian and three Japanese codes. Guides to these codes are shown in stylized drawings which are appended as Appendix A.

6.2 REPRESENTATIVE OPERATING CONDITIONS

The majority of primary conversion reactors in synthetic fuel production systems operate in the temperature and pressure ranges where hydrocarbon molecules can successfully be manipulated. Of particular interest here is the integration of hydrogen molecules into the complex bonding arrangement of higher hydrocarbons to achieve lighter fractions of higher hydrogen to carbon ratio. Another option is to reject carbon molecules and arrive at the desired ratio.

Simplified, it is the gap between the existing and the desired H:C ratio which determines the degree of severity of conversion operation, e.g., the temperature and the pressure. Superimposed is the partial pressure of hydrogen requirement.

Typical operating environments for the relevant processes considered here are:

- temperature - upto max. 1500°C (2800°F);
- pressure - upto max. 17,000 kPa (2500 psig);
- hydrogen content - min. 1% (weight), or 10,000 ppm and above.

6.3 BASIC CONSTRUCTION PRINCIPLES

The shop floor construction of a heavy walled pressure vessel may involve some or all of the components listed below. Each of these components may be identified as an individual cost centre associated with the shop construction of a heavy walled pressure vessel:

- . Cutting - of the incoming plate material to the required shape by either oxy-fuel gas or plasma flame cutting, followed by edge preparation by machining or flame cutting.
- . Forming - the prepared plates by rolling or pressing either hot or cold depending on the thickness and desired mechanical properties.
- . Forging - of the desired component to improve material property, design characteristics, geometry and to reduce welding.
- . Plating - or fitting up of the components items prepared for welding. Tack welding and the inclusion of strongbacks would be included in this activity.
- . Preheating - the components ready for welding using electrical induction, static or manual gas burners depending on accessibility, material type and thickness.
- . Welding - of the prepared components using manual, semi-automatic, mechanized or fully automated modes. The shielded manual arc welding (SMAW), submerged arc welding (SAW), electroslag welding (ESW), and gas tungsten arc

welding (GTAW) processes are usually employed for the welding of vessels and components. Gas metal arc welding (GMAW), flux cored arc welding (FCAW), and plasma arc welding (PAW) are other processes which may be used for various applications.

- . Inspection - using either non-destructive or destructive testing methods to determine that the fabrication conforms with the required code specifications.
- . Repairing Defects - although part of the welding and preheating requirements, will require special consideration for heavy walled vessels and will be an identifiable cost centre.
- . Cladding - may be considered as part of the welding and preheating requirements. Special consideration of materials and welding processes is necessary to meet the vessel requirements and minimize application costs.
- . Post Weld Heat Treatment - is necessary to relieve residual stresses and/or improve the metallurgical properties of the fabrication. It may be necessary to carry out this function in situ, on a local basis, or in a permanent furnace.
- . Non-destructive Testing - to determine that no discontinuities outside of the code allowables are present after post weld heat treatment.
- . Hydrostatic Testing - is carried out to ensure that the vessel is suitable for service under loading.

In addition to these items identified above, a Quality Assurance System must be in place and operating. This system is essential for ensuring that the incoming materials, all fabrication methods and procedures and all inspection methods and procedures are adhered to. Then, the assurance of the quality of the completed vessel can be documented. The control activities must be done to identify and confirm the quality at each stage of design, procurement and fabrication.

A Quality Assurance System should include the following key control items:

- design document control;
- material control;
- process control;
- welding control;
- examination and testing;
- non-conformance control;
- facility and equipment information;
- audit and surveillance.

Generally, it is more cost effective to manufacture correctly initially than to repair defects. A good quality assurance program can substantially improve the reliability of pressure vessels.

References: J.F. Harvey, 1974
R.W. Nichols, 1980

6.4 COMMON MATERIALS IN CONSTRUCTION

Once a process has been optimized for commercial applications, one of the most influential factors in the efficient (and safe) operation of the system is material reliability. Assurance of reliable service of a long-lead-time and difficult-to-replace conversion pressure vessel may be improved by the severe operating conditions under which the components must function. For coal gasification systems, the stream temperatures are as high as 1500°C (2700°F), and the pressures are near 8300 kPa (1200 psi). The liquefaction systems operate at lower temperatures and higher pressures.

The vessel sizes suggested by a number of conceptual designs to accommodate energy conversion process systems are larger than any that have been previously built, and as a consequence, will tax present processing technology for plates, forgings and piping to the limit.

Construction materials used for energy conversion vessels may be listed in the following categories:

- i) carbon steels;
- ii) low alloy steels;
- iii) high alloy steels;
- iv) forgings;
- v) piping steels;
- vi) overlays or cladding;
- vii) special linings.

Although the basis for most pressure vessel material

specifications is tensile strength properties and perhaps material toughness, a fine balance for heavy walled pressure vessels material specifications will have to be drawn from economics, availability, fabricability, weldability, sensitivity to embrittlement, material properties, (including toughness) service conditions and design-allowable stresses.

i) Carbon Steels

These steels are the most predominant used in the pressure vessel industry because of their low cost, availability, fabricability, weldability and their versatile mechanical properties. Between -28°C and 426°C , carbon steel is the most common material used in non-corrosive environments for oil refineries and chemical plants. For large, thick walled energy conversion vessels, carbon steels may be a viable consideration provided that they will be operated at temperatures below which creep occurs. An unacceptable compromise could result, however, in other problems such as condensate deposition and corrosion or erosion effects.

After long exposures to temperatures of about 418°C , the carbide phase of carbon steel may be converted to graphite. This phenomenon, known as graphitization, results in a lowering of the ultimate tensile strength and yield strength. Rupture of the steel could then occur.

The most common carbon steel used in heavy walled pressure vessels at this time is

SA-516 Gr.70, owing to its notch toughness or fracture resistant properties. Notch toughness is the ability of a material to absorb energy in the presence of a flaw. Heavier wall thicknesses require a higher level of notch toughness to ensure adequate resistance to brittle fracture, which is the most catastrophic event that could happen to a pressure vessel.

The plain carbon steels are generally limited to a thickness of about 200mm (8"). Other common carbon steels for pressure vessels either do not have the strength, (e.g., SA-285 Gr.C or SA-516 GR.55, 60 or 65) or lack the notch toughness, (e.g., SA-285 Gr.C., SA-515 Gr.70) of SA-516 Gr.70.

ii) Low Alloy Steels

Low alloy steels are the most common materials used in non-corrosive environments in the temperature range between 425°C and 650°C. Steels in this group, such as 1½ Cr-½ Mo, or 2½ Cr-1 Mo, are commonly specified for hydrogen service. Material types SA-387 Gr.11, Class 2, SA-387 Gr.22, Class 2 and SA-336, Class F22 are typical of these steels. For heavy walled vessels used in elevated temperature and/or hydrogen service as well as in a corrosive environment, a stainless steel overlay of one or two weld passes may be applied. Thus, the advantage of a relatively high strength, low cost base metal may be used while retaining the superior corrosion resistance

of the stainless steel.

However, material degradation may take place in these steels owing to hydrogen attack, hydrogen embrittlement, temper embrittlement, creep cracking and sulfidation attack.

iii) High Alloy Steels

High alloy materials (austenitic stainless steels and high-nickel alloys) provide excellent resistance to most process environments and have good high-temperature strength, but are not immune to environmental degradation. High alloy materials may also be easily fabricated and, for many grades, require no post weld heat treatment. Since the material is expensive, large thick walled energy conversion vessels will be operated below the creep range and will likely be built from carbon or low-alloy steels with stainless steel cladding. Erosion and temperature control may be maintained through refractory linings.

High alloy materials may be used for internal members of reaction vessels, transfer line pipe and fittings.

iv) Forgings

Forging courses may be processed from ingots where rolling capacities are limited. Flange rings, closure flanges and nozzles for pressure vessels are generally forgings.

The forgings, regardless of their manufacture, (by mandrel forging or ring rolling) are contour machined essentially to finished dimensions, austenized, quenched and tempered, and then finish-machined prior to use by the fabricator.

Typical forging materials such as SA-Z66, SA-182, Class F22, SA-182, Class F11 and SA-336, Class F22 may be used for heavy pressure vessel sections.

v) Piping Steels

Several different processes can be used to manufacture pipe for energy conversion processes. These processes can be grouped into three general classifications:

- wrought seamless pipe;
- welded pipe;
- cast pipe

The piping used for heavy wall pressure vessels will be governed by the American Standard Code for Pressure Piping, ANSI B31.3, "Petroleum Refinery Piping" and those materials identified in ASME Section VIII, Division 1.

Typical ASME carbon steel piping and tubes are SA-106 Gr.C, SA-210 Gr.C, SA-556 Gr.C2 and SA-557 Gr.C. Typical low alloy steel piping and tubes are SA-199 Gr.T11 and Gr.T22, SA-213 Gr.T11 and Gr.T22, SA-335 Gr.P11 and

Gr.P22, and SA-369 Grade FP11 and Grade FP22.

vi) Overlays and Cladding

Various methods and materials may be utilized to provide a corrosion resistant layer to the internal surface of pressure vessels. Continuously bonded cladding is necessary where cyclic conditions of temperature and pressure are encountered. The conventional methods for applying continuously bonded cladding to the interior of pressure vessels are hot rolling or roll cladding, brazing, explosion bonding, and weld metal overlaying or surfacing.

Hot rolling, brazing and explosion welding are generally done on a commercial industrial basis. Weld metal overlaying or surfacing is generally done by the fabricator during various completion stages of the vessel. Weld metal overlays may be achieved by the submerged arc, gas metal arc, shielded metal arc, or plasma arc welding processes. Welding consumables in the form of wires or strip, shielding gases or fluxes must be carefully selected along with proven welding procedures to minimize dilution and to ensure that the resultant weld deposits and transition microstructures are not crack sensitive. Similarly, the welding of clad steels must be accomplished by developing welding procedures and joint designs to provide a welded joint of the required metallurgical and mechanical properties.

Generally, weld metal cladding requires a two weld pass overlay with a minimum of 6mm thickness. The first pass, approximately 3mm in thickness, is accomplished using E308 L, E309 L or E309 CbL welding electrodes and the remaining 3mm in thickness by depositing E347 or E347 L filler metal with a 5-12% ferrite content as measured by the Severn Gauge. Additionally, 321, 316 and 317 L stainless steels and Hastelloy may be of particular interest for conversion vessel linings and attachments.

viii) Special Linings

Special refractory linings may be necessary to reduce erosion, reduce vessel wall temperature and provide additional protection against the corrosive environment. These linings may also be necessary for low-alloy piping. Refractory linings may be subject to cracking or spalling, thus allowing penetration of the corrosives to the vessel wall. Use of refractory linings should provide substantial cost benefits to the user through increased reliability and reduced maintenance costs.

6.5 TYPICAL CURRENT FABRICATION TECHNIQUES, INSPECTION AND SAFETY

6.5.1 FABRICATION - SHOP

The shop fabrication methods for pressure vessels depend considerably upon the fabricator's available equipment, techniques and fabrication philosophy. Maximized "streamlining" will need to be used for the new generation of heavy wall and very large pressure vessels to be cost effectively fabricated.

Since all vessels generally contain the largest tonnage component of courses or strakes, considerable fabrication costs are allocated to the fabrication of these components. The courses are either fabricated from plate or forgings. Fabricated plate requires rolling to size, edge preparation, longitudinal welding into "cans" and circumferential welding of the "cans" into courses. Forgings generally require only circumferential welding into the shell courses with other forgings or with fabricated cans.

Fabrication of a pressure vessel generally requires all of the principles previously presented in Section 6.3. Shop fabrication of vessels has a very distinct advantage over any field fabrication. That is, all fabrications can be made in a controlled environment where the use of welding processes and fabrication techniques may be maximized to provide the lowest construction cost.

The use of milling machines for edge preparations and high deposition rate welding processes further enhance the accuracy of fit-up and the productivity of the assembly. Turning rolls, welding manipulators, column and booms, and special jigs improve the ease and the economics of fabrication.

Particular attention must be given to welding heat balance and the control of distortion for pressure vessels. Attempting to correct distortion on a heavy walled low alloy vessel could degrade material properties and be extremely expensive.

The selection of the welding process for the welding of specific applications is influenced by factors such as position of the seam(s), joint configuration, quality requirements, heat input, and subsequent heat treatment. Welding processes for consideration have been identified in Section 6.3

Nozzles and other internal and external connections may be welded by manual, semi automatic, mechanized or fully automatic welding processes. Again, the careful selection of the welding process, procedures and joint designs can provide significant economic benefits while meeting the joint weld property requirements.

6.5.2 PREHEATING

Preheating generally in the range of 120°C to 230°C will be required before and during the welding of relatively heavy shell plates to prevent the form-

ation of cold cracks in the welded joints. The pre-heat temperature ultimately depends on the plate material, wall or plate thickness and the rigidity of the joint.

6.5.3 POSTWELD HEAT TREATMENT

The ASME Boiler and Pressure Vessel Code requires that the residual-stress condition caused by the welding operations be minimized by subjecting the welded vessel to a heat treatment at approximately 600 to 700°C.

Most codes will permit a localized heat treatment to take place on a girth weld and nozzle joints by circumferentially heating the entire part. However, in practice, the pressure vessel is heated as a unit. Localized heat treatments must be considered for field erected vessels.

The major purpose of the heat treatment involves removal of residual stresses, removal of cold work, providing dimensional stability and control of the toughness in the weld metal, base metal and heat-affected zones.

6.5.4 FABRICATION - FIELD

Where a vessel is too large or too heavy for complete shop fabrication and/or shipping, field fabrication and erection techniques will be necessary. Field erection is more complicated than shop fabrication. Efficiency and quality may suffer if adequate procedures and precautions are not defined and adhered to.

In particular, welding must be performed at elevated locations and in difficult positions. The use of automated welding equipment and processes is limited. The welding efficiency is generally less in field applications. Weather conditions may present special problems to schedules, procedures and quality. Work forces are generally less effective owing to local labour requirements and lack of long term teamwork. Forming equipment to correct poorly fitting parts is usually not available. Field work requires special versatile equipment, careful planning of material requirements and delivery co-ordination.

In conclusion, significant detail will be necessary for the field fabrication and erection of a heavy walled pressure vessel over and above that experienced by conventional technology.

6.5.5 NON-DESTRUCTIVE TESTING (NDT)

The procedural and acceptance requirements using non-destructive testing methods for pressure vessels and piping are identified in the ASME Boiler and Pressure Vessel Code, Section VIII, Divisions 1 and 2, and in the ANSI Pressure Piping Code B 31.3, Chapter VI.

The quality assurance procedures outlined in ASME Section VIII are intended to provide the minimum requirements to identify the inclusion of rejectable defects throughout the fabrication process. Emphasis should be placed on methods of detection during fabrication, thus reducing the possibility of extensive and expensive repairs after the fabrication has been completed. The ultimate responsibility of the degree, methods and timing of intermediate inspections lies with the fabricator.

Inspection and non-destructive testing must be extensive during the manufacturing cycle and include materials (forgings, bars, castings, plates, pipes, fittings, bolts and bolting materials), methods of fabrication (welding processes, procedures, part designs, preparation methods, machining finishes) and classes of materials.

Non-destructive testing methods used in the fabrication of heavy walled pressure vessels are included in ASME Section V and identified as follows:

- i) Ultrasonic testing, - Article 5
- ii) Radiographic testing, - Article 3
- iii) Magnetic particle, - Article 7
- iv) Liquid penetrant, - Article 6
- v) Visual examination, - Article 9

The Code specifies that each of the methods of inspection shall be in accordance with the appropriate section as identified above.

Major Inspection Concerns

Although significant cost reductions and integrity assurances can be derived from the use of NDT, greater benefits could be derived through selective improvements in the NDT technology. These areas include:

- i) Personnel training, qualification and certification.
- ii) The development of more comprehensive codes and procedures relating to visual inspection, defect acceptance criteria, anomalies between various codes and standards and interpretation of results.
- iii) The inspection technology, including reproducibility of results, improved understanding of the variables involved in optimized techniques, improved procedures, advanced instrumentation and better utilization and processing of the complex data that is available.
- iv) Better presentation and analysis of quantitative data for usage with fracture mechanics

and the need to characterize discontinuities for type, size and orientation.

In particular, the further development and usage of automated ultrasonics techniques, real time radiography, tomography and acoustic emission would improve on characterization of discontinuities and reproducibility of quantitative data through the use of computers.

In Service Examination

Safety and economics dictate that it will be necessary to perform periodic examinations or even continuous monitoring of the pressure vessel and piping to assure that the original required integrity has been maintained. These examinations may permit in-service corrections or maintenance to be made and thus, reduce the possibilities of component failure or unexpected shut-down. The key inspection areas relate to the development of in-service cracking (welds or underbead overlays), corrosion, hot spots and creep.

References: J.F. Harvey, 1974
J.F. Harvey, 1980
R.W. Nichols, 1980

6.6 CRITICAL ISSUES FOR THICK WALL PRESSURE VESSELS IN TYPICAL ENERGY CONVERSION SYSTEMS

A range of critical areas must be considered in the fabrication of steel and pressure vessels up to and including the installation site by designers, fabricators and project owners.

Beginning with the manufacturing of thick steel plate, the lamellar tearing of steel plates must be monitored and best, eliminated. It occurs when a plate is subjected to stress through the thickness. In this direction, the mechanical properties are generally inferior to those in other directions. The anisotropy is due to the presence of inclusions which become elongated during rolling. They are sulphides and oxides and are not uniformly distributed within an ingot, and therefore tend to cluster. During rolling, they interface to provide a long and easy path for fracture propagation. While ultrasonic examination of the plates is ineffective, the through thickness ductility of the steel can be measured by reduction of area measurements on tensile specimens cut with their lengths in the through thickness direction. This proved to be the most effective method for evaluating the tendency of lamellar tearing.

One of several other steel related potential problems requiring particular care is the deterioration in fracture toughness with time of 2½ Cr-1 Mo steel. This phenomenon includes temper brittleness and creep embrittlement primarily in the temperature range of

370 to 590°C. Depending on the operating temperature, if the steel operates in the creep range, the designer must be extremely cautious in applying this particular steel when designing in accordance with Division 2 of ASME Code Section 8.

As has been discussed in subsection 6.1.2, Analysis of ASME Code Section 8, Divisions 1 and 2 for North American applications at least, the fabrication of very large pressure vessels of very heavy wall thickness is not adequately treated as yet by the governing code. At this time, a considerable latitude in judgemental decisions is being left to the designer and fabricator in applying the rules of both Divisions. This situation may become critical by the time more of these vessels are being designed and fabricated, and therefore, it is critical to soon have a code amendment instituted to assure the fabrication of safe and reliable products.

Little experience is available with the operational behaviour of such vessels considered in this survey. The characteristics of their failure mode are unknown, and qualified input into the design, fabrication and the operation of such vessels based on actual operating experience is desperately needed. While a simulated numerical failure analysis could assist in eliminating this gap of uncertainty, an investigation into international accidents involving pressure vessels would be desirable. In this context, reference is made to the brief analysis of future pressure vessel designs in subsection 12.2.2.

In the process of pressure vessel design, a critical factor in location of fabrication and the effective cost of the erected pressure vessel is played by the mode, distance and type of transportation of the vessel from the fabrication shop to the installation site. Such constraints by size or weight are likely where the site is location inland from tidewater.

Most of Canada's relevant energy projects are located in Alberta and Saskatchewan. Access to these regions include:

- railroad from the West Coast;
- railroad from Ontario/Quebec;
- water and rail from the U.S. via the Mississippi River.

The transport weight limitation of 500 tonnes once existing for Northern Alberta - Syncrude 1977/78 - is now eliminated.

It is, however, still important for the vessel designer/fabricator to assure before fabrication the maximum dimensions permissible for selected or alternate transportation modes and routes.

On any major rail section in Canada, a limitation of 4.5 m outside diameter is likely existing. The combination of O.D. and vessel length is significant, though virtually any weight can be transported. Water transportation, of course, does not impose size limitation as do the railroads.

In some cases, very large vessels will have to be transported in sections. This imposes a high expenditure for the final circumferential weld in the field (with the same degree of quality control achievable in the shop fabrication). It also includes the final weld heat treatment to be carried out at the field.

In cases where a refractory type internal insulation is required for the operation of the pressure vessel, the transportation in a horizontal position over hundreds of thousands of miles of vibration-inducing railroad will likely destroy the integrity of the refractory. Therefore, refractory applications are mostly field applied processes, with all the limitations of field work associated, e.g., productivity, quality control and high cost.

An additional disadvantage may result from the need to protect the refractory of the pressure vessel from erosion or with an additional internal lining. This lining is commonly a thin sheet of stainless steel applied and welded to the vessel exits/nozzles.

Given the problem of transporting such very large pressure vessels to the job site, it would be desirable to identify in a comparative analysis, the relative merits of having these vessels assembled from prefabricated parts close to the job site. But rather than 'field-erected', have them 'shop-fabricated' in a fully furnished facility close to or adjacent to the erection site.

For further discussions of critical issues regarding material selection, design, fabrication and operation of heavy wall pressure vessels, reference is made to the comprehensive publications:

Re materials - D.A. Canonico et al, 1978

- W.E. Erwin, 1982
- Theodore Gottlieb, 1982
- T. Ishiguro et al, 1980
- C.W. Lawton, 1981
- C.D. Lundin, 1982
- J.T. McGrath et al, 1981
- Vinod K. Nangia, 1979
- L.I. Sluzalis, 1981

Re design/fabrication:

- M.J. Lavigne, 1979
- J.T. McGrath et al, 1981
- Y. Murakami et al, 1980
- W.R. Tyson et al, 1982
- J. Watanabe et al, 1977.

6.7 DEFINITION FOR THE PURPOSE OF MARKET SURVEY FORECAST

For the purpose of this market survey and forecast, a pressure vessel is defined in addition to the classical interpretation of the ASME Code as follows:

- operating at temperatures of more than 200°C (400°F);
- operating at pressure of above 30 bar (430 psig);
- operating with a hydrogen environment of 1% (weight) or 10,000 ppm and higher;
- will require protection against high degree of corrosion by cladding, lining, weld overlay or otherwise; and,
- having a wall thickness of 100 mm (2.5 inches) and thicker.

7. SYNTHETIC FUEL PRODUCTION SYSTEMS

The forecasted major use for crude oil in the long term is the production of transportation fuels. Primary requirements will be diesel fuels, jet fuels and gasolines. Light and heavy heating oils, particularly the latter, have already shown a significant decline over the past few years. Consequently, the synthetic fuel production systems must produce products for the refineries which are suitable for transportation fuel manufacturing.

The alternatives include the upgrading of heavy oil, the refining of bitumen derived from oil sand and the coal based conversion technologies for liquefaction and gasification. The latter has multiple applications as it may be used in the long term to replace natural gas in the manufacturing of methanol and to produce hydrogen for upgrading purposes and CO_2 to be used as a miscible and immiscible flooding agent in enhanced oil recovery projects. (Currently, natural gas is abundantly available at relatively low cost and it is being used as feedstock for the manufacture of methanol and hydrogen. Also natural gas and natural gas liquids, are probably being used in enhanced oil recover projects.)

During the mid-1970's when natural gas was believed to be a rather short-lived commodity, the regulatory authorities had given notice that the fuel must be reserved for its prime use - residential heating. Subsequent to the discovery of the "gas bubble" in Western Canada, restrictions have been lifted to the extent that today, an emergency situation of natural gas over-

supply and shortage of markets for the natural gas exploration companies exists. Manufacturers of methanol, ammonia, hydrogen, and in general, the emerging Western Canadian petrochemical industry, use this feedstock freely in current and developing project activities. However, the above-mentioned experience of the mid-1970's and the recent hearings in British Columbia into the proposed export projects based on natural gas, including other indicators, particularly by energy industry personnel and former politicians, suggest that a renewed interest in restricting the use of natural gas can be expected. Should the regulatory authorities disallow the use of natural gas for new projects - permitting the continuation of usage for existing operating projects - one could expect that the next logical feedstock would be the even more abundant coal in Western Canada. If, for the purpose of this study, one assumes that the described situation will take place during the forecasting period, the timing of such a decision is extremely critical for the demand of pressure vessels. In general, natural gas can be replaced in many applications by synthesis gas from coal, requiring extensive gasification facilities to generate the required amounts.

Following then, is the listing of alternative crude oil production systems or equivalents as they relate to the demand for very heavy pressure vessels:

- i) Heavy Oil Upgrading, Primary and Secondary Conversion.
- ii) Upgrading of Bitumen Derived from Oil Sands.

iii) Upgrading of Refinery Resids (Primary and Secondary).

iv) Liquefaction of Coal (Primary and Secondary).

Note: Secondary Upgrading is similar in all of the above mentioned alternatives as it relates to the further upgrading to specification and consumer products. (ie. naphtha to stabilized naphtha as a refinery feedstock for gasoline and light jet fuels, distillate to light products and gas oil to lighter products useful as refinery feedstocks).

v) Enhanced Oil Recovery - Generation of CO₂ from Coal via Gasification.

vi) Manufacturing of Hydrogen from Coal for Upgrading purposes.

vii) Generation of Transportation Fuels from Coal by Indirect Liquefaction via the Fischer-Tropsch technology (E.G., Sasol type technology).

Independent of the Canadian crude oil or equivalent supply and demand situation now and in the future, there will be projects undertaken which require pressure vessels that are similar to those in synthetic fuels production - methanol as power-station and automotive fuel mainly for export, and ammonia as fertilizer.

8. SYNTHETIC FUEL PROCESSES EMPLOYING THICK WALL PRESSURE VESSELS - (More detail process and relevant primary reactor descriptions are given in Appendices B to E inclusive).

8.1 HEAVY CRUDE UPGRADING

Heavy crudes like oil sand bitumen and conventional heavy oils have undesirable characteristics such as high viscosity, low hydrogen/carbon ratio, high sulphur, nitrogen and aromatics content and high metals concentration. The difference between various heavy crudes and conventional oils are highlighted in Table 8-1.

The objective of upgrading processes is to convert high boiling residual material to low boiling oil and reduce its sulphur, nitrogen metals and aromatic contents. Generally, two alternative routes are available for primary upgrading:

1. Carbon Rejection
2. Hydrogen Addition

Of the carbon rejection routes, the following processes are at various stages of development or implementation:

- Delayed Coking (Suncor);
- Fluid Coking (Syncrude);
- Flexicoking (Exxon & Research Engineering);
- Solvent Deasphalting (propane, pentane);
- Visbreaking or more severe thermal cracking;
- Eureka;
- Lurgi (dry-heat) process;
- Taciuk (UMATAK) Kiln process.

TABLE 8-1

COMPARISON OF VARIOUS CRUDE COMPOSITIONS AND PROPERTIES

	Athabasca/Cold Lake Bitumen	Saskatchewan Heavy Oil	Light Conventional Alberta Crude	Alsands Target Synthetic Crude
Gravity, API	8-11	11-25	37-40	34-36
Sulphur, %wt.	4-5	2-5	0.3-0.6	0.1-0.15
Nitrogen, %wt.	0.2-0.4	0.2-0.5	0.1	0.05
<u>Composition, %vol.</u>				
Naphtha 1BP-204°C	0-4	0-10		
Distillate 204-343°C	5-15	10-20		
Gas Oil 345-560°C	35-45	30-40		
Residue 560°C+	43-53	40-50		
		C ₃ -C ₄	3-4	3-5
		Naphtha C ₅ -105°C	22-24	15-20
		Distillate 150-345°C	35-37	35-45
		Gas Oil 345-560°C	27-30	33-38
		Residue 560°C+	8-10	NIL

Most of these processes operate at high temperatures 400 to 1000°C, and low pressures less than 340 KPa. They are described in detail in Appendix B. The hydrogen addition route is followed by several technologies which are at various stages of development:

Catalytic Hydrocracking

- LC-Fining (Lummus);
- H-Oil (Hydrocarbon Research Inc.);
- Veba Oil;
- Gulf HDS process;
- Aurabon (UOP);
- Unicracking/HDS (Union Oil) and HOC (Kellogg);
- HDS/FCC (Atlantic Richfield);
- Shell Moving Bed Process;
- Dynacracking (Hydrocarbon Research Inc.);

Non-Catalytic Hydrocracking

- CANMET (Petro-Canada)

The above are described in Appendix C. In this case, reactors and associated vessels generally operate at relatively high severity. For example, the CANMET process involves the cracking of heavy crudes at an elevated temperature (460°C) and high pressure (14 MPa) in a hydrogen rich atmosphere. In addition, there are combination processes like Dynacracking, proposed by HRI. It combines thermal hydrocracking and Flexicoking in a single reactor.

Although there is a variety of possible upgrading schemes, there are several general similarities regarding unit operations associated with the primary upgrader. To demonstrate the nature of these facilities, Figure 8-1 is included to show a typical pro-

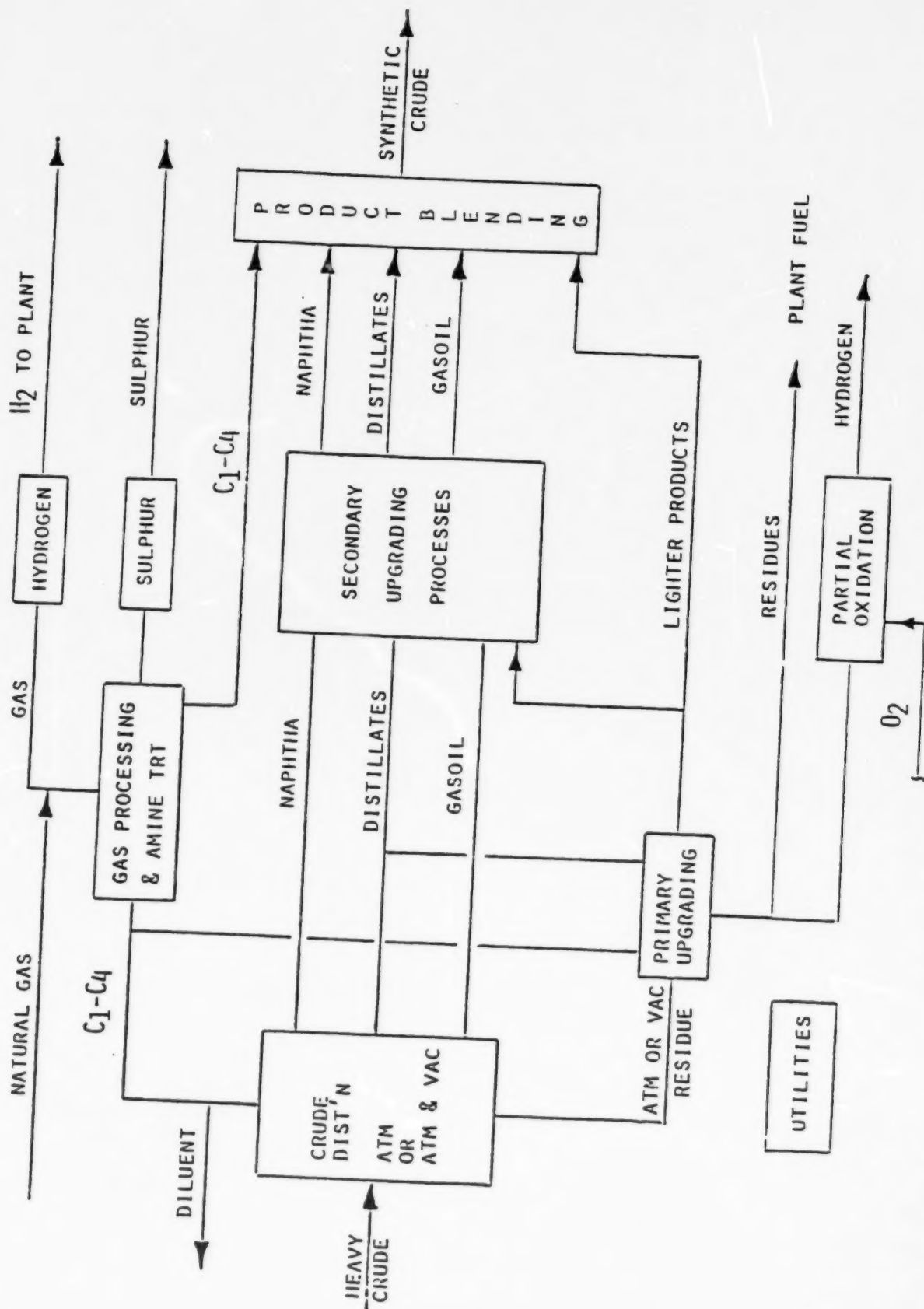


FIGURE 8-1. PROCESSING SEQUENCE FOR UPGRADING

cessing sequence capable of upgrading crude from a conventional heavy oil area. The diluted heavy crude entering the plant is desalted and then fed to a distillation tower to yield 'straight-run' gasoline, naphtha, distillates and residue. This residue is fed to the primary upgrader and further separated into gases, naphtha, distillates, gas oils and residue. In the case of coking processes, the fuel residue is in the form of coke. In most cases, the lighter products from the primary upgrader plus some of the straight-run products are of poor quality and must be subjected to secondary upgrading. Here, certain fractions such as naphtha, distillates and gas oils are hydrotreated for further nitrogen and sulphur removal. The hydrotreated naphtha, distillates and gas oil fractions are then blended with lighter material, (e.g., C_4) to form the synthetic crude. Generally, the residue from the primary upgrader is not blended into the synthetic crude and must be consumed internally as plant fuel or fed to a partial oxidation unit for hydrogen production.

In addition to the main process units, the upgrading plant will include other support facilities:

- hydrogen plant;
- gas recovery unit;
- amine unit;
- sour water stripper;
- sulphur plant;
- tail gas clean-up;
- utilities plant.

Of the support processes, the only one which would require many pressure vessels as defined here is the hydrogen plant. A single train hydrogen plant generating about $91 \times 10^3 \text{ Nm}^3/\text{hr}$ of hydrogen from natural gas by steam reforming requires, exclusive of compression, approximately 13 pressure vessels ranging from 1.2 m diameter knock-out drums to 4.8 m diameter x 3.6 m high shift converters and operating up to 2.6 MPa. The compressor for such a hydrogen capacity to raise the pressure from a shifted and cleaned value of about 2.0 MPa would require approximately 12 pressure vessels from .6 to 1.2 m in diameter and 2.4 to 5 m long, assuming four stage compression. A plant of this size would provide approximately one-half of the hydrogen required for a Syncrude size secondary upgrading plant.

8.2 COAL LIQUEFACTION

8.2.1 GENERAL

The ratio of hydrogen to carbon in coal is lower than in most liquid hydrocarbons and the liquefaction of coal involves the addition of hydrogen to the coal, separation of the coal into a hydrogen-rich fraction and a hydrogen-lean fraction or a combination of the two.

To liquefy coal, four basic routes can be pursued, viz:

- catalytic hydrogenation;
- solvent extraction;
- thermic depolymerization or pyrolysis;
- indirect liquefaction via gasification.

Except for indirect liquefaction, these process principles are overlapping; they operate at temperatures above 350°C in presence of liquid phase (slurry oil, solvent) of strong solvent characteristics. In all cases, a thermal destabilization takes place. The stabilization of radicals and unsaturates takes place by combination with hydrogen and condensation as competing reactions. Condensation reactions might involve, for example, radical recombinations generating high molecular bonds.

The purpose of the solvent is multi-functional and includes hydrogen transfer, while the mineral com-

ponents of the coal, particularly the finely distributed pyrite, exert a substantial catalytic action.

Generally, when hydrogenating about 100 parts of coal (maf) with 2 to 6 parts hydrogen, a yield of up to 70 parts of oil and hydrocarbon gases can be achieved. The remaining non-distillable portion, which also contains the minerals in the coal, can be used for gasification to yield hydrogen for further use in the process.

The coal derived oil contains primarily aromatics, phenols and naphthenics, and partially aliphatic components. Its light and middle distillates yield fuels and chemical feedstock. While coal gasification combined with the Fischer-Tropsch Arge synthesis, yields mainly paraffins and olefins, the hydrogenated coal oil offers the production of aromatics. Thanks to its high aromatic content, coal derived oil fractions are well suited for the production of high octane gasoline fuels, while Arge Fischer-Tropsch synthesis derived higher paraffinics make a good feedstock for the production of diesel and aviation fuels, sufficiently high in cetane value. Coal gasification and liquefaction complement each other if a widespread product slate is required in the market place. This synergism was utilized in German refineries during the 1930's and 1940's when both process routes covered a significant component of the country's demands.

When using weak hydrogenation, solid and liquid extracts are derived that are environmentally compatible and can be used as middle or heavy heating oil. These

fuels are characterized by low sulphur and ash contents.

Coal derived oil can be further used as feedstock for the production of non-fuel products, e.g., electrodes.

In all processes, where coal is hydrogenated, the feed coal is actually ground and, process depending, dried and de-ashed. Following this, it is slurried with process derived oil or solvents and then pumped to the desired pressure and heated to process temperature. A significant problem in commercial scale coal-to-liquids plants, is the separation of solids. While filtration and sedimentation are satisfactory in laboratory pilot plants, distillation appears to be the practical method for large scale operations.

The four routes to liquid fuels from coal are described in more detail in the following subsections, while the relevant process descriptions are contained in Appendix D.

8.2.2 CATALYTIC HYDROGENATION

Although catalytic hydrogenation processes are an extension of the liquid solvent category, it may be argued that they have several unique characteristics. Operating temperatures and pressures are partially governed by the choice of catalysts and common ranges are approximately 400 to 450°C and 17.0 to 25.0 MPa. Hydrogen is added directly to the coal in the presence of a catalyst, and the latter can be disposable or recycled in the process.

Catalytic hydrogenation of coal to liquids can be accomplished by intimate mixing of coal and catalyst (e.g., Bergius process developed by I.G. Farben in 1927, and modern versions such as the Saarberg and Ruhrkohle processes) or by a catalytic bed reactor (e.g., fixed, fluidized, entrained, molten or ebullating beds as in the H-Coal process).

In I.G. Farben technology the catalyst usually cannot be recovered and therefore an inexpensive material is required. The catalyst developed for the Bergius process was iron oxide.

Conflicting statements can be found in the literature regarding product slate flexibility for both catalytic hydrogenation and liquid solvent processes. It is agreed, however, that both process categories can handle a wide range of coal types.

It is also generally accepted that the development limitations of the hydrogenation process are very similar to those of the solvent process. Typical mechanical problem areas include the high pressure, large scale slurry feed system; the pressure let-down facility; and the liquid-solid separators.

8.2.3 SOLVENT EXTRACTION

Solvent extraction may be accomplished with:

- (i) Hydrogenated solvent without hydrogen, e.g., the Consol Synthetic Fuel process (CSF) - Conoco Development Co.;
- (ii) Hydrogen and non-hydrogenated solvent, e.g., the Solvent Refined Coal process (SRC) - Gulf Mineral Resources Co.; and
- (iii) Hydrogen and hydrogenated solvent, e.g., the Exxon Donor Solvent process (EDS) - Exxon Research and Engineering Company.

Liquids produced by solvent extraction can be of high quality and two of the modern processes which have reached demonstration scale development employ solvent extraction and include the Gulf SRC II and Exxon EDS processes.

Yields for solvent extraction processes are dependent on the boiling range of the solvent and the nature of the recycle oil. Generally the lighter the solvent the greater the liquid yield. However, this consideration has to be weighed against optimization of process variables such as temperature and pressure. Also it is suspected that certain constituents of the coal ash act as a catalyst in the distillation reaction. Extensive research needs to be done in this area since further understanding could greatly enhance oil yields.

Solvent extraction processes are more desirable than pyrolysis or hydrocarbonization owing to their lower

operating temperatures (ca 450°C). In addition, solvent extraction offers more flexibility than pyrolysis in matching product slate and market requirements. This advantage has been demonstrated on non-commercial plants on a wide variety of North American and European coals.

8.2.4 PYROLYSIS OR HYDROCARBONIZATION

Pyrolysis is basically the heating of coal in a non-oxidizing atmosphere followed by partial condensation of the volatiles. Therefore, it can be viewed as an extension of the traditional low temperature and low pressure carbonization. In both these processes carbon is removed in the form of tar. Extremely quick heating of the feed coal and a short residence time results in greatly improved yields compared to low temperature carbonization. The conversion of feed coal to tar is about 30 to 60% by weight.

As this process is conducted under mild operating conditions, the liquid yields are comparatively small relative to other liquefaction processes. The produced tar is reactive (pyrophoric) and can only find use in combustion or gasification for further processing. Unlike the other liquefaction processes, pyrolysis enhances the calorific value (relative to the feed coal) and therefore represents an upgrading for lignite or other low rank coals.

The liquids, usually heavy, are extensively cracked and require hydrotreating. The main product is char which must be gasified if clean fuels are to be produced.

Several companies (e.g., Occidental Petroleum, Rockwell International, Union Carbide, Lurgi and FMC) have been testing this type of process. Both the COED and Occidental Processes operate at approximately atmospheric pressure. However, this advantage is offset by the need for high capital and operating costs associated with gas compression and cleanup. Also storage and transportation of tar is extremely difficult because of the tar's pyrophoric behaviour. This factor has severely limited commercialization of the process.

8.2.5 INDIRECT LIQUEFACTION

The most outstanding single process in this category is the Fischer-Tropsch synthesis route to liquid fuels. SASOL (South African State Oil and Gas Company) has used this process in the only commercial operating coal liquefaction plant in the world today. Despite the poor transferability of the South African economics to Western industrialized countries, it has nevertheless developed a large interest in North America.

Indirect liquefaction is achieved by gasifying coal to a mixture of carbon monoxide and hydrogen from which liquid hydrocarbons are synthesized, either directly by the Fischer-Tropsch synthesis route or via the methanol route using the Mobil process.

The lower efficiency of the gasification and Fischer-Tropsch reaction is mainly attributed to the high breakdown temperature of coal into hydrogen and carbon monoxide and the subsequent synthesis to large molecules. Furthermore, gasification processes are sensitive to coal feed size, moisture content and caking characteristics. In addition the plant offers limited flexibility relative to changes required in product slate. A further liability, depending on location and market conditions, is the large number of by-products such as oxygenated compounds, tars and phenols which must be conveyed away from the plant possibly without receipt of credits.

The first SASOL plant has been operating since 1955 and produces a wide variety of products including gasoline and gaseous fuels. This older plant employed both fixed bed and fluidized bed reactors. The fixed catalyst bed could not be scaled up, but the fluidized bed unit, leading to a lighter, more aromatic product has been scaled up in SASOL II which is designed to produce about $6050 \text{ m}^3/\text{d}$ (38,000 barrels) of liquid hydrocarbon fuels per day. A third plant, (SASOL III) is currently under construction for operation in early 1990.

This route favours low rank coals compared with other liquefaction processes. Disadvantages of this route are high capital costs and high coal consumption due to low thermal efficiencies.

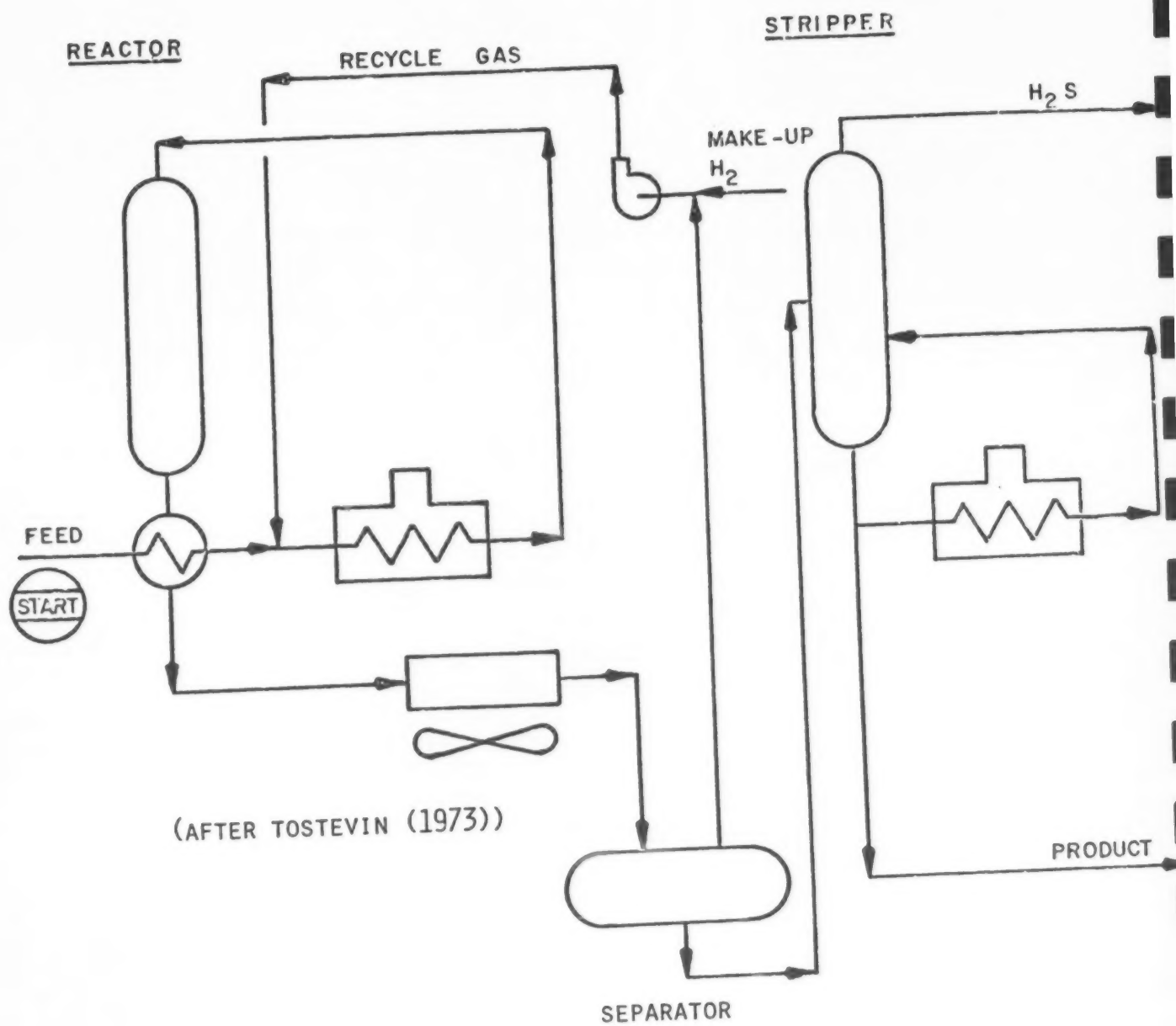
8.3 SECONDARY UPGRADING /HYDROTREATING

Further to the primary upgrading or liquefaction processes, secondary upgrading or hydrotreating of the intermediate products is required. This is of particular interest because these processes call for equipment operating at moderate or high pressure in the presence of molecular hydrogen.

In most cases, the lighter products from the primary upgrader plus some of the straight-run products are of poor quality and must be subjected to secondary upgrading to render them suitable as refinery feedstock. Naphtha, distillates and gas oils are hydrotreated for further nitrogen and sulphur removal and are then either blended with lighter material to form the synthetic crude, or directly fed into the refinery. Generally, the residue from the primary upgrader is not blended into the synthetic crude and must be consumed internally as plant fuel or used in a partial oxidation unit for hydrogen production. A typical hydrotreater flowsheet is shown in Figure 8-2.

Hydrotreater processes and equipment represent well established technology. The hydrotreating units associated with the Syncrude plant to process $22,300 \text{ m}^3/\text{d}$ (140,000 bbl/day) of feed are typical of those required for a bitumen or heavy oil upgrading installation based on coking. In the Syncrude plant, the coke distillate is hydrotreated to two ranges - naphtha and butanes (C_4 -230°C)

FIGURE 8-2
TYPICAL HYDROTREATER



and gas oil ($230^{\circ}\text{C}+$). In each case, there are two process trains to carry out the hydrotreating.

The naphtha hydrotreating section operates at about 4,000 kPa (500 psia) and temperatures in the range of 160° - 350°C . Each train comprises three reactors - a diolefin reactor and two naphtha reactors. In each case, the reactor is operated in a down flow fixed bed mode with intercooling to minimize catalyst deterioration from overheating. A recycle stream of hydrotreated product equal to about 10% of the fresh feed is used. The vessels are approximately 33 m in diameter and range in length from 15 m for the diolefin reactor, to 6.6 m for the second naphtha reactor. In addition, a cold separator operating at about 3,000 kPa (450 psia) and 3 m diameter by 12 m length is required. A knock-out drum about 1.8 m in diameter by 6.6 m length is also required for each train. These vessels are all about 65mm wall thickness. Total requirements amount to five vessels per train or a total of ten vessels for the naphtha hydrotreater plant.

The gas oil hydrotreaters operate at higher pressure than the naphtha treaters and require heavier vessels for this reason. The gas oil hydrotreaters operate at 10,000 kPa (1500 psig) and about 400°C . Each of the two gas oil hydrotreaters comprises of two pairs of 3-bed arrangements - a guard reactor and two hydrotreater beds in a second reactor. The reactors are about 3m in diameter and the guard reactor about 6.6m high with the main reactor being about four times as high. These also operate as fixed bed,

down flow reactors. In addition, each plant requires a hot separator, a cold separator and an amine contactor for H_2S removal. The two separators are about 3m in diameter by 12 m long, while the amine contactor is about 3m in diameter by 42 m high. The main hydrotreater vessels have about 125 mm walls, while the amine contactor is about 75mm thick. Vessels required then are about eight per hydrotreater train, or sixteen for the gas oil hydrotreater plant.

8.4 COAL GASIFICATION

Coal gasification involves the reaction of the carbon in coal with steam to generate CO and H₂. This reaction is endothermic so energy must be supplied to make the reaction proceed. This is done most generally by oxidizing a portion of the coal with either oxygen or air.

Three general reactor types are used in gasification - fixed or moving bed, fluidized bed and entrained - and examples of all three types have been designed for operation at elevated pressures. The most advanced gasification processes for pressure operation are:

- | | |
|---------------------|-----------------------------------|
| Fixed or moving bed | - Lurgi; |
| | - BGC Lurgi. |
| Fluidized bed | - HTW (High Temperature Winkler); |
| | - Davy Winkler. |
| Entrained | - Texaco; |
| | - Shell; |
| | - Saarberg-Otto; |
| | - Bi-Gas. |

The number of pressure vessels required for a coal gasification plant will differ between plants due to the flowsheet and equipment design used, but they are basically similar. The coal is raised to reactor pressure either with lock-hoppers or slurry pumps and injected into the reactor with carrier liquid or gas or by screw feeder. Downstream of the reactor, pressure vessels are required for separation of the phases. If the ash is removed separately from the gas stream, a cyclone operating at reactor pressure is required. In addition, for operational reasons, it is usually preferable to

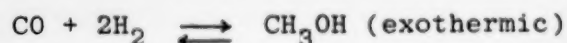
cool or quench the hot product gas before throttling to lower pressure. The ash is removed either dry, through lock-hoppers or as a water slurry of quenched slag particles and the ash removal train is not exposed to hydrogen.

Descriptions of the individual gasification processes are included in Appendix E.

8.5 METHANOL AND AMMONIA SYNTHESIS

8.5.1 METHANOL SYNTHESIS

Since the 1920's, methanol has been produced commercially by the generalized reaction:



From an equilibrium point of view, this reaction is favoured by:

- low temperatures (being exothermic), although reaction rates would be slower;
- high pressure of reactants (note 3:1 mole ratio of reactants to products);
- excess H_2 (if maximum carbon conversion is desired) which shifts the equilibrium balance to the right and also assists in dispersing the heat of reaction.

The following data illustrate the effects of the H_2/CO ratio on the equilibrium yield at 300°C and a total system pressure of 29,700 kPa:

H_2/CO Ratio	Percent CO Converted to Methanol	Volume Percent Methanol in Exit Gas
2:1	83.2	62.3
6:1	98.0	14.1

These data are for single-pass conditions in which equilibrium is reached, (i.e., choice of catalyst is not pertinent).

For either case above, the unreacted CO and H₂ can be recovered and recycled rather than wasted, but it should be noted that excess H₂ promotes methane formation as a co-product.

The question of proper H₂/CO ratio is similar whether the initial raw material is natural gas or coal. For natural gas, one starts H₂-rich and uses the reverse shift reaction to bring up the CO concentration. For coal, one starts H₂-poor and uses the shift reaction to bring up the H₂ concentration.

The era of very high pressure (35 MPa) methanol processes ended in the early 1970's. Today, low-pressure processes dominate the market. For example, up to capacities of about 1000 t/d, Lurgi low pressure methanol plants are designed for pressures of about 5-7 MPa in the synthesis loop. In the case of large plants, pressures of up to 10 MPa are provided in the synthesis to reach larger single-train capacities.

Important features of a typical low pressure reactor system are shown in Figure 8-3. The catalyst (main component is copper) is inside the tubes of two parallel reactors needed for large capacity with circulating gas preheated in a single heat exchanger. The two reacted gas streams unite at the outlet of both reactors and flow through the heat exchanger.

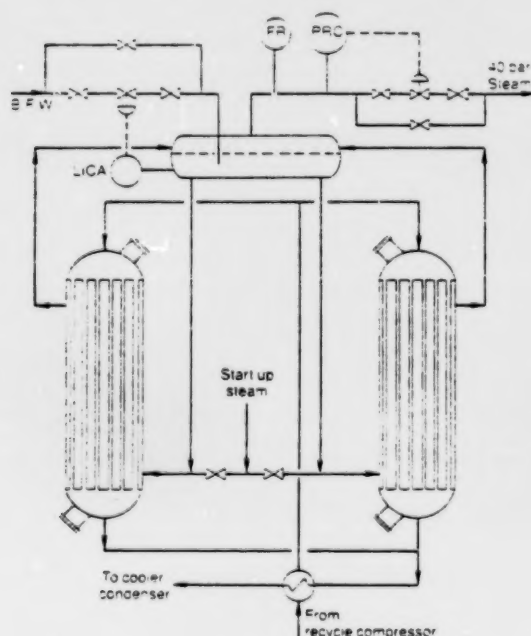


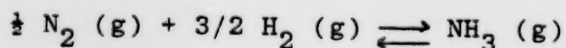
FIGURE 8-3
LURGI BOILING WATER LOW-PRESSURE METHANOL
REACTOR FOR 2,500 STPD PLANT

Typical projects currently constructed/completed include:

Company	Location	Capacity	Announced Cost
Alberta Gas Chemicals Ltd.	Medicine Hat, Alta.	Expansion of 1200 t/d	\$130 Mill.
Celanese Canada Inc.	Edmonton, Alta.	2100 t/d	\$255 Mill.
Ocelot Industries	Kitimat, B.C.	1200 t/d	\$160 Mill.

8.5.2 AMMONIA SYNTHESIS

Ammonia is produced by reacting hydrogen and nitrogen in the presence of an iron catalyst according to the reversible reaction:



This reaction is highly exothermic and produces a conversion to ammonia of 14% at about 15.2 MPa, 500°C.

The flowsheet shown in Figure 8-4 can be divided into three major sections, viz: a compression system; conversion facility and product recovery system. Synthesis make-up gas consisting of 3 parts hydrogen and 1 part nitrogen with or without inert components is compressed and introduced into a circulating synthesis loop where it is combined with unreacted recycle gas. Following the ammonia synthesis reaction, the ammonia is condensed from the unreacted gases and stored.

Modern plants usually have a design capacity over 600 t/d and operate in the pressure range 14-24 MPa (Slack, 1973). The current trend is to design conversion on the basis of the quench-type principle using one to several catalyst beds, depending on loop pressure. Figure 8-5 shows an ICI quench converter which can be employed for trains with capacity in the range 500-1650 tpd. The converter contains a continuous bed of catalyst surrounding a central heat exchanger. Gas flows up through the

shell cooling annulus, down through the exchanger, up a second annulus, down through the catalyst bed, up through the other side of the exchanger, and out of the top exit. Quench gas enters from the top and is injected into the bed at two points by specially developed distributors. Typical data for ICI Quench Converter are given in Tables 8-2 and 8-3. Owners or licencees of commercial ammonia production processes include KELLOG, CHEMICO, BASF, UHDE, OSW, FAUSER-MONTECATINI, GRANDE PAROISSE, FOSTER WHEELER-CASALE, ICI, PRITCHARD, TOPSOE, CHEMOPROJEKT, JAPAN CONSULTING INSITUTUE AND BRAUN. For details on these processes and information on synthesis loop design operation and materials of construction, the reader is referred to Slack (1973).

(ICI loop for tube-cooled converter - After Slack (1973))

- Key:
- | | |
|--|--|
| 1 - Reciprocating synthesis gas compressor | 9 - Refrigeration cooler |
| 2 - Reciprocating circulator | 10 - Secondary liquid ammonia catchpot |
| 3 - Tube-cooled converter | 11 - Liquid ammonia let-down vessel |
| 4 - Circulator oil filter | 12 - Liquid ammonia storage |
| 5 - Synthesis gas oil filter | 13 - Refrigeration compressor |
| 6 - Air or water cooler | 14 - Refrigeration condenser |
| 7 - Feed/effluent exchanger | 15 - Synthesis gas cooler |
| 8 - Primary liquid ammonia catchpot | 16 - Alternative position for circulator |

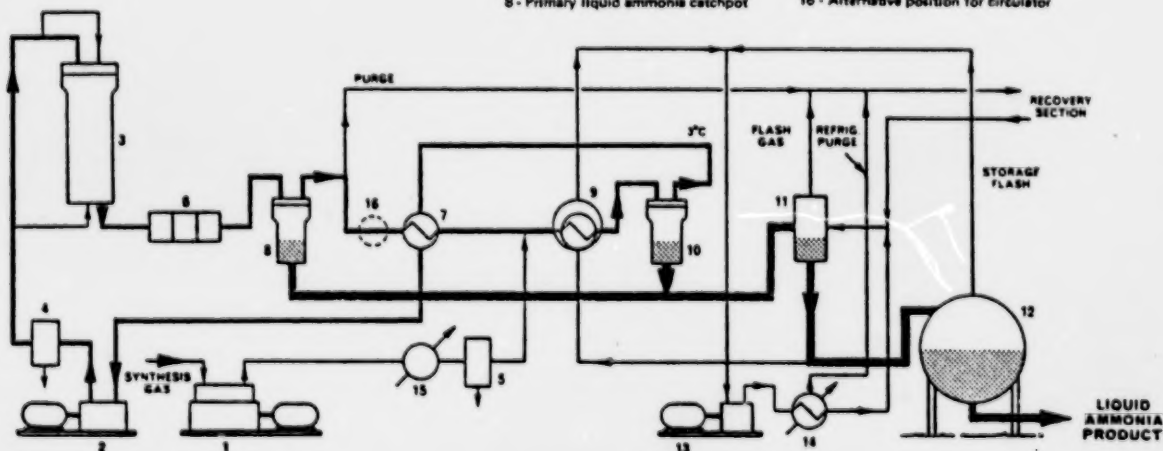


FIGURE 8-4
FLOWSHEET FOR AMMONIA SYNTHESIS

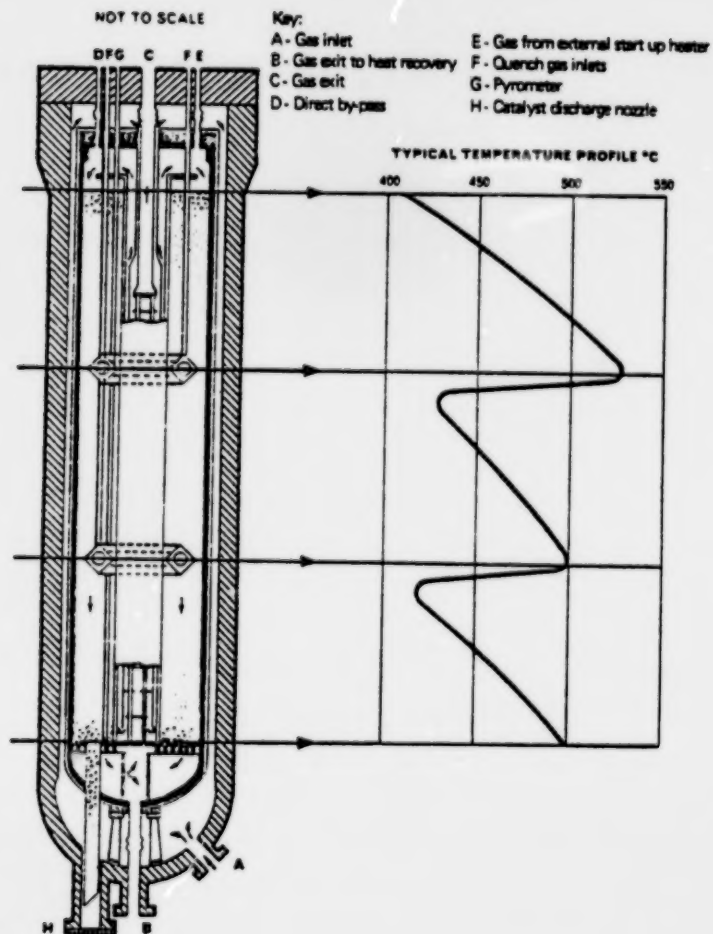


FIGURE 8-5
ICI QUENCH-TYPE CONVERTER
(after Slack, 1973)

TABLE 8-2

Typical Data for ICI Quench Converters of Various Sizes

Capacity, short tpd	660	990	1100	1650
Pressure, psig	4700	3200	4250	3220
Inlet gas composition, %				
Ammonia	4.0	3.0	3.2	1.4
Inerts	15.0	12.0	15.0	12.0
Inlet gas flow, MM scfh	10.6	18.0	18.5	24.5
Catalyst volume, ft ³	740	1170	1100	2400
Pressure vessel				
Internal diameter, in.	80	96	95	109
Length, in.	437	493	472	700
Weight, short ton				
Cartridge shell	14.2	34.2	22.8	56.4
Heat exchanger	15.5	30.0	25.4	23.8
Pressure vessel (less cover)	130	128	182	240

TABLE 8-3

Typical Data for ICI Quench Converter of 1,300 STD Capacity

Pressure, psig	2200	3200	4000	4700
Inlet gas flow, ^a MM scfh	25.8	21.2	19.8	19.0
Catalyst volume, ft ³	2600	1730	1320	1030
Pressure vessel				
Internal diameter, in.	120	102	96	89
Length, in.	663	606	528	488
Weight, short ton				
Cartridge shell	68.5	40.8	29.2	23.6
Heat exchanger	37.1	25.4	20.7	17.9
Pressure vessel (less cover)	186	184	187	189
Converter pressure drop, psi	140	104	87	91

^aInlet gas composition: 2% NH₃, 12% inerts (CH₄ + A).

Planned ammonia projects, (Anon, 1981) for construction/completion in the near future are:

Company	Location	Capacity	Announced Cost Est.	Planned Start-up
Esso Chemical	Redwater, Alta.	Ammonia 1600 t/d Urea 1500 t/d	\$300 Mill	Mid-1983
Sheritt Gordon Mines Ltd.	Ft. Sask., Alta.	Ammonia 1100 st.t/d Urea 700 t/d UAW Solution 300 t/d	\$265 Mill.	Early-1983

8.6 PROCESS EVALUATION AND FORECAST OF TECHNOLOGY

Of all the synthetic fuel production systems currently available or developing - as summarized in Table 8-4 - for application in Canadian energy projects, few are commercially proven and most are at various stages of developmental maturity.

For the various users of upgrading processes, it appears that the oil sands project operators presently favour the more proven carbon rejection technologies such as fluid coking or Flexicoking. The use of these technologies for this application will likely continue well into the 1990's.

To obtain better yields of liquid transportation fuels from heavier than 16⁰ API processes of greater severity such as the catalytic hydrocracking processes, are required. In this group, for the operation of stand-alone heavy oil upgraders, the LC-Fining, the H-Oil and the Veba Oil processes are in very close contention, for their very similarity. On average they are not as well commercially proven as the coking processes, but given extensive pilot plant tests with the relevant feedstocks, few operating problems are expected. So, for the forecasting period one or all of these processes will likely become the standard for the upgrading of heavy oils.

Exxon's Flexicoking process is a possible contender for several upgrading applications, however, it shows

TABLE 8-4 - SYNTHETIC FUEL PRODUCTION SYSTEMS

(Involving Heavy Pressure Vessels)

SECONDARY UPGRADING *

- NAPHTHA HYDROTREATING;
- DISTILLATE HYDROTREATING;
- GAS OIL HYDROTREATING.
- Applicable to Heavy Oil and Bitumen Upgrading and Direct Coal Liquefaction.

PRIMARY UPGRADING OF HEAVY OIL

- CARBON REJECTION: COKING PROCESSES (DELAYED, FLUID, FLEXICOKING, SOLVENT DEASPHALTING, VISBREAKING, EUREKA, DIRECT COKING) ARE MOSTLY LOW PRESSURE.
- HYDROGEN ADDITION: CATALYTIC HYDROCRACKING:
 - LC-FINING;
 - H-OIL;
 - VEBA OIL;
 - GULF HDS;
 - AURABON UOP;
 - UNICRACKING/HDS & HOC;
 - HDS/FCC;
 - SHELL;
 - DYNACRACKING.

NON-CATALYTIC HYDROCRACKING:

- CANMET.

LIQUEFACTION OF COAL

- DIRECT LIQUEFACTION:- EXXON DONOR SOLVENT;
- SOLVENT REFINED COAL SRC-I, SRC-II;
- H-COAL;
- NEW GERMAN TECHNOLOGY (RUHRKOHLE/VEBA/SAARBERG);
- CITIES SERVICE/ROCKWELL HYDRO-PYROLYSIS.
- INDIRECT LIQUEFACTION: - FISCHER-TROPSCH SYNTHESIS.

GASIFICATION OF COAL

- BI-GAS;
- LURGI;
- BGC/LURGI;
- WINKLER - DAVY & HTW;
- TEXACO;
- SHELL;
- SAARBERG-OTTO.

somewhat greater application limitations.

While many of the megaprojects may continue to linger on the drawing boards, a number of smaller sized upgrading plants may well be installed in the mid and long term. It is likely that in cases of $1592 \text{ m}^3/\text{d}$ (10,000 b/d) or $3185 \text{ m}^3/\text{d}$ (20,000 b/d) plant sizes much less complex and less costly partial ungrading processes like deasphalting, visbreaking or single stage hydrotreating, will be employed.

A potentially external factor may in the future play a role in the selection of upgrading processes - the availability of low cost natural gas as feedstock for the generation of hydrogen. It is conceivable that if hydrogen, of which the hydrogen addition processes require great amounts, becomes more expensive the operators of heavy oil upgraders may tend to favour the carbon rejection type of processes.

It should be noted here that presently, the Alberta Oil Sands Technology Research Authority (AOSTRA) jointly with eleven industry companies and CANMET are evaluating all the available and developing processes for upgrading purposes. The emphasis in this study is on the compatibility of the processes with the Athabasca derived bitumen. The results of the study will be available in late 1982.

As for the coal liquefaction processes, it is of note that none of the direct coal liquefaction processes are currently commercial. At best, a phase of pilot/

demonstration performance will be required before sufficient confidence for investment in commercial plants can be achieved. Currently in an advanced state of pilot testing are the processes of HRI, Exxon and Ruhrkohle/Veba with capacities of about 600 to 200 t/d while several other process developers have pilot facilities with capacities of a few tons per day.

Several issues need to be addressed before commercialization is reasonably possible:

- i) catalyst activity and longevity (H-Coal and New German Technology);
- ii) complete understanding of potential process flexibility and reliability with respect to production of marketable products;
- iii) compatibility of primary conversion processes with secondary upgrading, e.g., hydrotreating, as commonly used by the petroleum industry;
- iv) scale-up criteria for the design of commercial size equipment; and,
- v) detail testing of feedstock/process compatibility.

Similarly as for the direct hydrogenation processes, the solvent refined coal processes (SRC-1 and SRC-2) require demonstration plant proving before commercialization. While SRC-1 is progressing to that stage, the SRC-2 6,000 t/d demonstration project slated for construction in Morgantown, Virginia, has been halted by its sponsors in 1981.

Of all the liquefaction processes, the Fischer-Tropsch route as operated by Sasol in South Africa is the only commercially proven one. For application in Canada, very large revisions would be expected, particularly relating to the product slate. Contrary to the current South African practice of producing a wide spectrum of industrial and fuel gases, liquid fuels and chemicals, a Canadian Fischer-Tropsch based plant would likely produce diesel fuel and gasoline at a process-dependent range of ratios. Because of its long term commercial record, this technology is quite attractive for potential project operators.

Therefore, in the attempt to predict emerging coal liquefaction technologies during the forecasting period, the likely significant selection parameters will be the product marketing and feedstock suitability. While the more efficient conversion processes, the direct hydrogenation processes, will likely be commercial within a decade, the following development scenario, based on coal liquefaction is likely to develop for Canada:

- i) a $1592 \text{ m}^3/\text{d}$ (10,000 b/d) to $3185 \text{ m}^3/\text{d}$ (20,000 b/d) demonstration plant will be installed in either the Maritimes or Western Canadian provinces during the latter part of the 1980's producing by 1990;
- ii) the technology used will be either direct hydrogenation or a modified solvent type of process;
- iii) a commercial sized plant of about $7962 \text{ m}^3/\text{d}$ (50,000 b/d) or $9554 \text{ m}^3/\text{d}$ (60,000 b/d) will be operational by 1996; and one additional one by the year 2000;

- iv) the technologies used will be in one case direct hydrogenation or modified solvent, and in the second case a Fischer-Tropsch type synthesis technology, or the Mobil M type process from coal via methanol to gasoline.

Regarding the technology to derive liquid fuels from natural gas, e.g., methanol or gasoline or similar, it is considered possible that developments will occur in Canada during the forecast period. An evaluation or forecast for the purpose of this report, however, was considered outside the scope of study.

With respect to coal gasification systems, the high temperature and high pressure systems appear to be favoured in most of the evaluations. While the selection of gasifiers is dependent to a high degree on the feedstock and the end use of the gas, for the generation of synthesis gas for further processing to methanol, ammonia, hydrogen or CO₂, based on Western Canadian coals, the modern developments of Shell, Texaco and Saarberg-Otto appear to be most promising. As many U.S. systems developed during the 1970's have been stopped, the Bi-Gas process is currently being tested in a pilot plant in the U.S. Similar to the coal liquefaction situation, the Koppers-Totzek system has extensive international experience in gasifying various feedstocks for different uses. Because of its commercial track record, many project planners prefer this system despite its economic drawbacks (non-pressurized, large volume) over the more efficient but less proven systems.

For the application of coal or coke gasification in the mid term, the Texaco gasification system is clearly the favorite. It may experience strong competition in the 1990's, however, from such developing systems as the Shell and Saarberg-Otto gasifiers. The Texaco gasification system has the unique advantage of extensive commercial experience in gasifying heavy refinery residu. As such, it will also be used in many of the forecasted heavy oil upgrading projects.

The economics of coal liquefaction in a Canadian context, particularly in Western Canada, are considerably more attractive than commonly published study reports on U.S. projects suggest. Particularly with the increased oil prices for synthetic oil production as per the September 1, 1981 Energy Pricing Agreement between Ottawa and Alberta and subsequent amendments, the typical Western Canadian advantages for coal liquefaction have improved. British Columbia and Alberta have vast resources of relatively low cost coal which has little, if any, sulphur content. Also both Provinces have abundant natural gas available at low cost for the generation of hydrogen, and many of the low cost coals are very well suited for liquefaction. In all of these counts, the U.S. situation, particularly with respect to eastern coals, is vastly less promising. Table 8-5 summarizes the forecast of process technology for the evaluated energy conversion options.

TABLE 8-5

PROCESS TECHNOLOGY FORECAST

OILSANDS: Coking type processes will be used for Alsands as planned and for Canstar. Subsequent projects will employ hydrogen addition type processes, e.g., H-Oil and LC-Fining, for their higher yield.

HEAVY OIL UPGRADING: Hydrogen addition Processes (e.g., H-Oil, LC-Fining or Veba Oil) will be used exclusively for projects of 6370 m³/d (40,000 b/d) and larger. Smaller upgraders could make use of the less complex processes (e.g., Visbreaking, Single Stage Hydrotreating or Deasphalting).

COAL LIQUEFACTION: For direct liquefaction the hydrogenation processes will dominate, (e.g., Ruhrkohle/Veba/Saarberg or H-Coal); while the Fischer-Tropsch technology or similar will represent the indirect coal liquefaction.

COAL GASIFICATION: For gasification of coal in such end use applications as methanol, ammonia, hydrogen, carbon dioxide or in Fischer-Tropsch synthesis, the high temperature and high pressure gasifiers will be used - Shell, Texaco, Saarberg-Otto. Of these, Texaco has the advantage of being most developed and having extensive commercial experience in oil resid gasification.

METHANOL AND AMMONIA SYNTHESIS: Will use currently-available commercial technology.

9. OUTLOOK ON CANADIAN ENERGY PROJECTS

9.1 ENERGY PROJECTS ANNOUNCED

During the late 1970's and up to 1981, several project forecasts were made by public and private agencies/companies. However, the most comprehensive overview appears to be the report by the Major Projects Task Force on Major Capital Projects in Canada to the Year 2000, issued in June, 1981 (Carr/Blair, 1981). The complete listing of "Detailed Inventory of Major Canadian Projects to the Year 2000, Appendix F", is contained in this report also as Appendix F. Of the identified hydrocarbon/fossil conversion related projects, 26 would use very heavy wall pressure vessels. These projects are abstracted from the referenced list and set out in Table 9-1.

While this listing only reflects the project planning or development status as of February 28, 1981, many companies have since retreated rather than pushed forward and have relaxed the timetable for project implementation, i.e., introduced delays or have downscaled a project. In subsection 11.1, Likely Canadian Energy Projects, an analysis is presented of those of the projects perceived likely to go ahead including their timing.

In his address to the Sixth Canadian National Energy Forum, the Federal Minister of Industry, Trade and Commerce, Herb Gray (Canadian National Committee, 1981) identified a list of proposed megaprojects to the year 2000 with total investment of \$438.5 billion. Of this amount, \$379.8 billion would relate to energy

TABLE 9-1
HYDROCARBON/FOSSIL CONVERSION
RELATED PROJECTS

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST \$ MILLIONS	COST, PEAK FORCE	OPERATING MANPOWER	CONSTR. PERIOD FROM-TO	COMMENTS
Unknown	Ammonia Plant	Newfoundland	200			1981-82	
Unknown	Methanol Plant	Newfoundland	100			1981-82	
Ultramar-Golden Eagle Refinery	Heavy Fuel Oil Upgrader	Montreal	1500			1982-85	7.9-9.5 x 10 ³ m ³ /d
Petrostar/Suncor	Cat. Cracker for Resid. Oil	Quebec City	150			1980-82	
Busky et al	Residual Oil Upgrading	Sarnia	500			1983-86	72 x 10 ³ m ³ /d
Ocelot/Potash Corp.	Heavy Oil Upgrading	Lloydminster	1000		200	1981-86	Min. cap. of 4.8 x 10 ³ m ³ /d
Esso Resources Canada Ltd.	Ammonia and Fertilizer		300				
Gulf Canada	Cold Lake In-Situ Oil Sands	Cold Lake	7000	6885	2400	1981-89	22 x 10 ³ m ³ /d
Xova/Petro Canada	Sundalta Oil Sands Mining	FT. McMurray Rgn	10000			1986-90	
Shell Canada et al	Oil Sands Mining	Fort McMurray	10000			1985-90	21-22 x 10 ³ m ³ /d
Suncor	Peace River In-Situ	Peace River	5000	5000	2000+	1985-92	22 x 10 ³ m ³ /d
Syncrude	Alsands Project	Fort McMurray	7200	8185	3200+	1980-87	2.1 x 10 ³ m ³ /d
Unknown	Oil Sands Plant Exp.	Fort McMurray	185	750	175	-81	9.5 x 10 ³ m ³ /d
Alberta Gas Chemicals	Plant Exp. 3rd Train	Fort McMurray	1500		1000	1984-86	
A.O.S.T.R.A.	Combustion Pilot Plant	Cold Lake	100			1985-87	Expansion to 2.4 kt/d
Canadian Fertilizer	Methanol Plant Expansion	Medicine Hat	130	400	100	1979-82	
Celanese Canada Inc.	Synth. Oil Upgrading Plant	Edmonton	200			1980-83	
City of Medicine Hat	Ammonia/Urea Plants	Medicine Hat Rgn	255			-82	
Esso Chemical Canada	Methanol Plant	Redwater	200+			1990's	
Petro Canada	Coal Gasification Pilot	Hardisty	345			1980-82	Expansion to 660 kt/y.
Various with Fed/Prov. Gov't	Ammonia/Urea Fert. Plant and Plant Expansion		800		300	1983-86	16 x 10 ³ m ³ /d
B.C. Hydro	Heavy Oil Upgrading		1800		800	1988-91	
Ocelot Industries Ltd.	Coal Gasification/Liquefaction	Hat Creek	2000			1988-96	
Westcoast Transmission	Coal Petrochemicals	Kittimat	5000		3500	1983-90	7.9 x 10 ³ m ³ /d
Unknown	Coal Liquefaction	Kittimat	140			1980-81	1.2 kt/d
	Methanol Plant	Northeast B.C.	175			1981-82	
	Ammonia Plant		200			1981-82	

SOURCE: CARR/BLAIR, (1981).

development. While the category "Conventional Hydrocarbon Exploration and Development" of \$78.1 billion includes oil and gas development in the Arctic and offshore, "Heavy Oil" is allocated \$42.7 billion. Table 9-2 identifies the breakdown of expenditures on the proposed megaprojects to the year 2000.

TABLE 9-2

PROPOSED MEGAPROJECTS TO 2000 AD		
SECTOR	TOTAL EXPENDITURE (\$ BILLION CURRENT)	% OF TOTAL EXPENDITURE
ENERGY:		
CONVENTIONAL HYDROCARBON EXPLORATION & DEVELOPMENT	78.1	17.8
HEAVY OIL DEVELOPMENT	42.7	9.7
PIPELINES	31.6	7.2
PROCESSING & PETROCHEMICALS	28.5	6.5
ELECTRICAL GENERATION & TRANSMISSION	198.9	45.3
ENERGY SUBTOTAL	379.8	86.5
OTHERS:		
FOREST PRODUCTS	7.7	1.8
MINING	19.9	4.5
PRIMARY METALS PRODUCTION	6.2	1.4
TRANSPORTATION	6.4	1.5
MANUFACTURING	13.4	3.1
DEFENCE	5.1	1.2
SUBTOTAL	58.7	13.5
TOTAL	438.5	100

9.2 CANADIAN ENERGY DEMAND FORECAST

Many forecasts of oil demand, prices and supply capability have barely survived appearing in print before being outdated. In the following attempt to establish a basis of demand for synthetic crude oil production, of course, exactly the same risk is incurred. During the year 1981, several major events occurred which potentially changed the Canadian energy scenario significantly. In June, 1981, the National Energy Board completed and issued its "Canadian Energy, Supply & Demand, 1980-2000" report (National Energy Board, 1981), which is based on the statements and forecasts of the major energy companies in Canada. Because of the comprehensive evaluation and the detail of data forecast, this report is considered the most appropriate source of information for the purpose of this study. Most of the submissions then provided to the NEB were influenced by the intentions of the National Energy Program (NEP) of October, 1980. This program had caused a reduction of enthusiasm by the energy industry for future synthetic fuel production (Government of Canada, 1980).

In the forecasts of pre-NEP vintage, most submitters were confident in identifying the start-up date for mining type and in-situ type oil sands plants; however after the introduction of the NEP industry, with one exception, had no comments as to the future of oil sands projects - see Table 9-3.

TABLE 9-3
INDUSTRY RESPONSE TO NEP

PROJECTED START-UP DATES OF POTENTIAL OIL SANDS PROJECTS
1980-2000

Comparison of Forecasts
Pre-NEP

	Syncrude Expansion	Cold Lake In Situ	Alsands Mining	4th Mining	2nd In Situ	5th Mining	3rd In Situ	6th Mining	7th Mining
CPA	1988	1986	1987	Five unidentified projects: 1990-200					
Dome	1995	1986	1988	1990	1993				
Gulf	1988	1987	1988	1990		1995		2000	
Imperial	1988	1986	1987	1993					
Norcen	1987	1986	1986	1990	One unidentified project every 22 years				
NOVA	1988	1987	1988	1991		1994		1997	2000
Ontario	NIL	1987	1987						
Petro-Canada	1989	1987	1987	1990	1994	1997	1999		
Shell	1988	1987	1987	Three unidentified projects: 1993, 1995, 1999					
Texaco	1985-1990	1985-1990	1985-1990	Two unidentified projects: 1990-1995					
Union Carbide	1985	1987	1987	1993	1990	1994	1996	1999	2000
AERCB	1989	1987	1987	Several unidentified projects: 1991-2000					

PROJECTED START-UP DATES OF POTENTIAL OIL SANDS PROJECTS
1980-2000

Comparison of Forecasts
Post-NEP

	Syncrude Expansion	Cold Lake In Situ	Alsands Mining	4th Mining	2nd In Situ	5th Mining	3rd In Situ
CPA	NIL	NIL	NIL				
Dome	—	—	—				
Gulf	NIL	NIL	NIL				
Imperial	NIL	NIL	NIL				
Norcen	—	—	—				
NOVA	NIL	NIL	NIL				
Ontario	NIL	1988-1991	1981-1991	NIL	NIL		
Petro-Canada	1939	1987	1987	1990	1994	1997	1999
Texaco	1985-1990	1985-1990	1985-1990	Two additional unidentified projects 1990-1995			
Union Carbide	—	—	—				
AERCB	NIL	NIL	NIL				

— Forecast not available

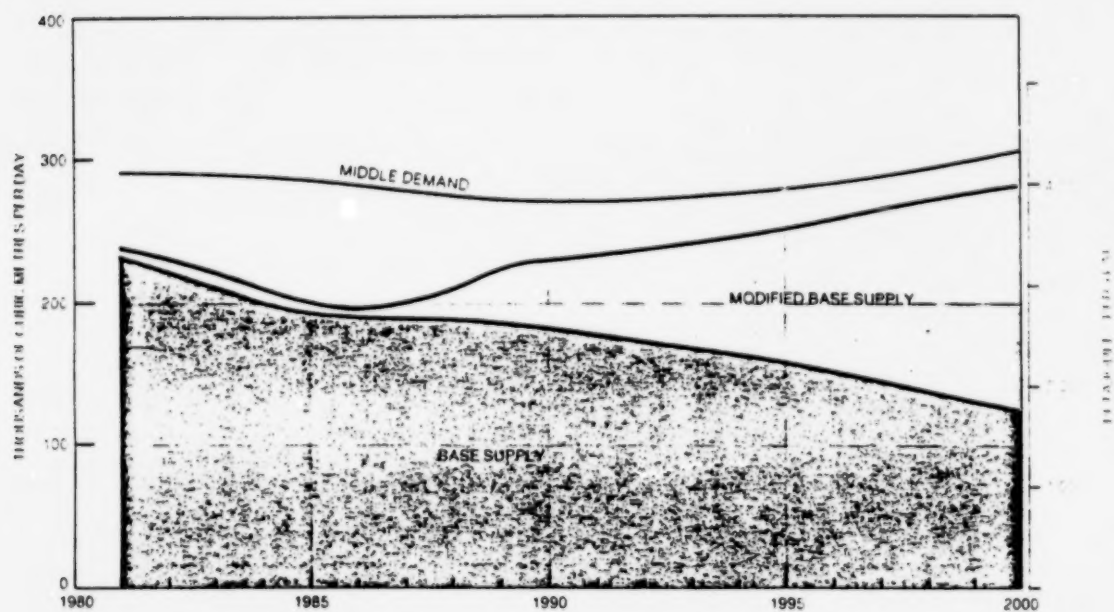
Source: National Energy Board, 1981

A significant event, the signing of the Energy Pricing Agreement of September 1, 1981, between Ottawa and Alberta was considered to have an effect of encouragement for several energy projects, had the development of the world oil price reasonably appreciated along an upward tending path. However, with its dramatic downturn, the oil price during the latter part of 1981 and, particularly, the first quarter of 1982, probably wiped out much of the immediate term advantages the Energy Pricing Agreement would have resulted in (Governments of Canada and Alberta, 1981).

It is therefore concluded that the base case of demand of oil and equivalent and the supply as identified by the NEP in its report are a reasonable basis for the current forecast. Figure 9-1 represents the NEB's forecast of supply and demand - crude oil and equivalent base case supply with middle demand. The base supply includes the currently established reserves for light crude oil and the expected reserve additions, in addition to pentanes plus, some oil sands and frontier production and upgraded heavy oil. Of the heavy crude oil, established and additional anticipated reserves are included, as well as pentanes plus and contributions by oil sands plants. Subtracted are upgrader feedstock capacities and some upgrading losses.

For the purpose of the current forecast, to arrive at a conventional light crude oil equivalent production, all frontier production and heavy oil upgrading production is subtracted. The difference between the forecasted middle demand and the forecast conventional crude oil and equivalent production represents the supply gap, which may or may not be filled by the production from

FIGURE 9-1
SUPPLY & DEMAND-CRUDE OIL & EQUIVALENT
BASE AND MODIFIED BASE SUPPLY WITH MIDDLE DEMAND

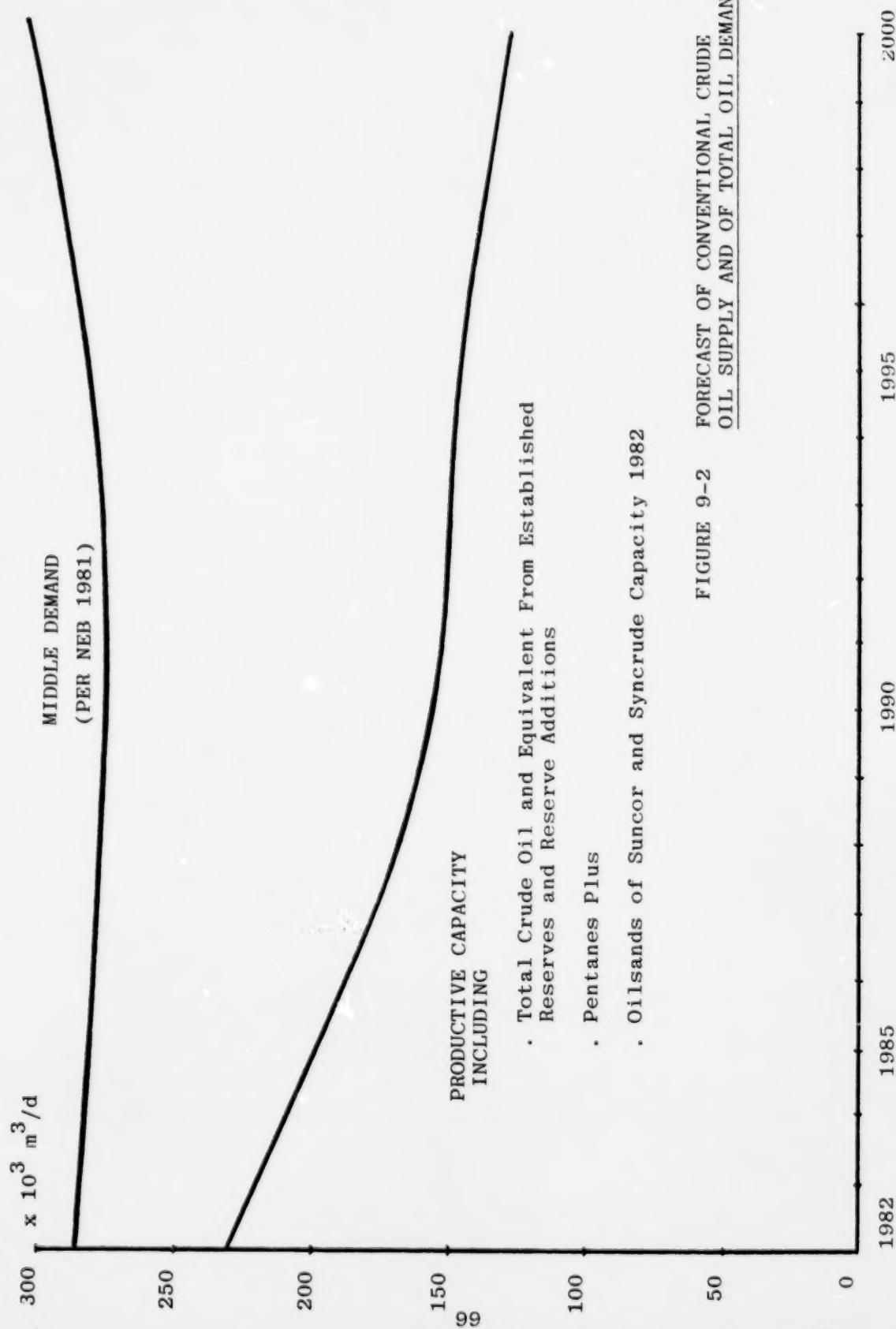


Source: National Energy Board, 1981 (Also see Table 9-3)

frontier and synthetic production systems - see Figure 9-2.

It should be noted here that the development of the world oil price is the single most important factor relating to the Canadian self-sufficiency in crude oil, e.g., the ability to produce all the oil required, eliminating any oil imports. Presently in Canada imported heavy oil supported by the import subsidy is more economical for refineries than Canadian produced heavy oil. A moderate additional drop in the world market price for light oil will render entirely uneconomic Canadian new oil that is priced under the new oil reference price structure.

For the purpose of this forecast, it is assumed that the current drop in world oil price is more of an upset rather than the establishing of a new trend. This assumes strong price appreciation during the second part of this decade, and further, that the relevant Canadian governments will cause the economic climates for the energy industry to be sufficiently attractive to exploit Canada's vast energy resources, rather than import crude oil from the world market at high socio-economic costs. Consequently, this forecast assumes that self-sufficiency in crude oil or equivalent will be reached in Canada by 1995. Most of the submitters to NEB's 1981 hearing were rather divided as to the possibility of reaching self-sufficiency before the year 2000. It is assumed here for the good economic sense it would make to stimulate Canadian industry rather than that of OPEC countries.



It follows then, that the level of crude oil or equivalent import increases from currently 55,000 cubic meters per day to about 88,000 cubic meters per day by about 1985 with subsequent reduction to about 85,000 cubic meters per day in 1990, and with increasingly more synthetic oil production and frontier oil production coming on-stream, a net import reduction to zero by 1995.

Not included in this forecast for light crude oil or equivalent, is the development of the petrochemical industry as it relates to the production of methanol and ammonia. In addition, the oil forecast used here excludes the possibility of the regulatory authorities refusing permission for natural gas as industrial feedstock at some time during the forecast period. Any replacement of natural gas as a feedstock for generation of methanol, ammonia or hydrogen would likely result in a drastically increased application of coal conversion technologies, e.g., liquefaction and gasification.

9.3 RELEVANT GOVERNMENT POLICIES

9.3.1 FEDERAL

9.3.1.1 THE NATIONAL ENERGY PROGRAM

The National Energy Program, introduced on October 28, 1980, caused the single most significant effective change of the energy industry in Canada in recent years. Its major policy elements are the Canadianization of the energy industry and the diversion of emphasis from mainland oil to the Canada Lands. This tends to shift the control from the private industry to the Federal Government. In the process, Canadian exploration and production firms should benefit.

As part of the NEP (Government of Canada 1980), the Government of Canada has provided an incentive program that covers maximum 80% of incentive payments to any company of 75% Canadian ownership rate(subsequently reduced to 65%) for qualified exploration expenditures on Canada Lands. Any lower Canadian Ownership Rating (COR) as it would be applicable for the multi-national companies and some of the internationally active Canadian companies would result in sharply reduced incentives.

This structure is particularly conducive to the development of the offshore interests of Canadian companies. During 1981 and early 1982, it has in-

creased the pressure on heavy oil upgraders and oil sands projects to become competitive with offshore oil.

Although heavy crude oil processing plants are by definition of the NEP considered for income tax purposes as a resource activity, instead of a manufacturing and processing plant, the sponsor companies feel that the treatment is not sufficient to put an upgrader into a competitive scenario with offshore oil.

Consequently, the hydrocarbon upgrading or oil sands or coal conversion industry will have to find innovative ways to be competitive with offshore oil and gas, unless the timing of the offshore developments is retarded by Federal/Provincial disagreements over the distribution of rights to the resource.

9.3.1.2 THE OFFSHORE INCENTIVE PROGRAM

The trend has been set by the National Energy Program that the exploration for oil and gas on Canada Lands has the highest priority by the Federal Government with respect to incentives and taxation. Most of the attractive offshore acreage had been acquired earlier by the multi-national companies and, subsequent to the introduction of the NEP, many of the Canadian companies sufficiently powerful to make use of these incentives, found insufficient acreage available to utilize the incentives. With the introduction of Bill C-48, however, the Federal Government provided the vehicle of redistributing much of this attractive yet currently unworked acreage by distributing it to companies of sufficient Canadian ownership rating. During 1981 and early 1982, the effects of this policy have become apparent in that several Canadian companies have acquired rights from multi-national companies, via farm-in agreements, or else purchased the multi-national's rights entirely. While the actual distribution of unworked acreage has not yet taken place, a list of "interested parties" is being drafted in Ottawa.

The incentive basically comprises 80% of forgivable grant in monthly installments. No other government controls, tax incentives or any other incentives can match this attractive feature, exposing any exploration company to not more than 20% risk.

Regardless of external influences (e.g., world oil price), the exploration for oil on Canada Lands will be irresistably attractive to Canadian investors, potentially syphoning-off investment funds from other energy projects.

9.3.1.3 THE OTTAWA/ALBERTA ENERGY PRICING AGREEMENT

This Federal/Provincial Energy Pricing Agreement had been delaying many energy developments in the country for over two years. While Alberta basically requested the pricing of its hydrocarbon resources at near world price, Ottawa, in protecting the Central and Eastern Canadian customer, disallowed this pricing and declined permission to export at attractive international price levels. On September 1, 1981, an agreement was finally reached between Canada and Alberta. In essence, it puts old oil (discovered before December 31, 1980) at about 75% of world price estimated over a schedule of the next five years. The new oil discovered after the above date, or manufactured from synthetic oil plants is priced at world level, but not above a schedule beginning with \$45.95 per barrel as of January 1, 1982. While both Governments hailed this agreement as a victory, industry felt that the agreed incentives were insufficient to carry the great risk inherent with large energy projects.

Already, in March, 1982, this agreement is partly outdated because the world oil price did not increase as anticipated in the Agreement. This situation will likely cause a delay of several years which, coupled with the currently rather modest taxation incentives for heavy oil upgrading and oil sands projects, increase the reluctance of project sponsors to commit to go-ahead on their projects.

9.3.2 PROVINCIAL

While all provinces have energy policies, few could exert any significant impact and improve the currently economically unattractive situation for project sponsors.

9.4 INFLUENCE ON CANADIAN ENERGY PROJECTS BY WORLD OIL PRICE DEVELOPMENTS

Despite all initial reluctance by the industrialized nations to accept OPEC's domination of the international oil scene, Canada's oil price schedules of the NEP as well as of the Ottawa/Alberta Energy Pricing Agreement are based on the world oil price development. And, while having discovered the taste for hefty increases of this world oil price to spur the development of alternative energy options, Canada as well as the U.S. and some European countries find now the dependence on OPEC's downward price development less satisfying.

The growing glut in the world oil market that has developed during 1981 and which is strengthening in '82 has forced most of the major oil exporters to severely reduce exports. Saudi Arabia is pressed by other OPEC members to cut production by as much as 30% (Calgary Herald, February 20, 1982).

The market deterioration has reached such a degree of severity that Britain has decided to cut its North Sea oil price by U.S. \$4.00 after having already reduced it by U.S. \$1.50 per barrel to maintain its export levels (Globe & Mail, March 3, 1982). This follows a worldwide development of stagnating oil prices for almost a year, of drastic reductions of oil flows and of a substantial increase of world oil reserves.

In its December 28, 1981 issue, Oil & Gas Journal summarizes the current situation as follows:

Hammered by both recession of industrial economies and conservation induced by high oil prices, world oil production in 1981 suffered its biggest year-to-year decline in history. It plunged 3.57 million b/d - an even 6% - to 55.9 million b/d.

The slump in non-Communist oil flow was still greater - 3.93 million b/d or 8.7% to just 41.28 million b/d. Production in Communist areas, thanks entirely to a Soviet gain, rose 2.5% to 14.61 million b/d.

Brunt of the world production decline was absorbed by the Organization of Petroleum Exporting Countries. OPEC oil flow plummeted 16.9% to 22.35 million b/d from 26.89 million in 1980. That stacks up against the OPEC peak of 31.28 million b/d in 1977.

The percentage decline in most OPEC countries, however, was far greater than the overall average indicates. Excluding Saudi Arabia, which kept production high most of the year in a battle to reunify gyrating oil prices, the OPEC decline averaged 26.3%.

The big drop in OPEC flow turned non-Communist production downward despite a healthy gain in other non-Communist countries. Non-OPEC flow rose 3.3% to 18.92 million b/d. Spurred by higher crude prices, production by this group of countries has increased each year since 1975 and is up 35.7% for the 6-year period.

World reserves of crude and condensate jumped 22.2 billion bbl or 3.42% to 670.7 billion bbl, with the entire gain coming in non-Communist areas. The non-Communist total rose 22.64 billion bbl to 584.86 billion.

Communist reserves fell 455 million bbl to 85.8 billion as a result of declines in China and most of the smaller producers in the bloc.

Estimated gas reserves also rose sharply, soaring 272.8 trillion cu ft to an all-time high of 2,911 trillion. Non-Communist areas chalked up a highly respectable gain of 32 trillion cu ft to a new high of 1,716 trillion. But the lion's share of the world increase came in Communist areas,

where a Soviet re-evaluation hiked its claimed "explored reserves" total to 1,160 trillion cu ft. The Communist areas gain was 240 trillion cu ft to a new high of 1,194 trillion.

World refining capacity, despite depressed demand and plant closures in some regions, held virtually flat this year, rising only 97,570 b/d or 0.12% to 81.44 million b/d. Non-Communist capacity slipped 400,000 b/d (0.62%) to 64.9 million b/d. But this was counteracted by a Communist area increase of 496,500 b/d to 16.53 million. Communist percentage gain was 3.1%.

While this development may be only a temporary upsetting of the trend, delaying further oil price increases along expected schedules by a few years could mean the changing of a trend. This trend would demonstrate that the industrialized nations as the major oil consumers have learnt to live with a considerably reduced energy supply. If the latter should prove to be the case during the following years, then likely, a major and derogatory effect on the Canadian energy industry will be felt. It might mean that the current energy structure will have to be changed again, in order to entice industry to continue exploration for conventional oil, however, predictions for this scenario are not being made here.

In an interview reported in the Calgary Herald, (March 5, 1982) Wayne Minion, Chairman of the Alberta Petroleum Marketing Commission, indicated that he foresees a lack of markets for about 32,000 m³/d (200,000 b/d) of Alberta's prime light oil during the coming summer. This shut in production - representing about 1/6 of Alberta's daily

production - would be more than was shut in during Alberta's production cutbacks last year to protest the National Energy Program.

Minion indicates that refiners can now buy oil on the spot market for about \$36 per barrel and collect an \$18 Federal subsidy, which results in the net cost for imported light crude oil of \$18 as opposed to Alberta light oil at about \$25, including transportation cost.

The reason for this paradoxical situation is that the Canadian Oil Import Compensation Program is supposed to compensate for the price difference between foreign and domestic oil. It is based, however, on the average cost of the contracted import oil, and does not take spot market prices into consideration. In earlier years, when the international crude oil market was at its peak, spot market prices often hovered at \$7 to \$8 above long term contract prices, whereas currently, discounts of \$4 to \$5 are experienced because of over supply.

While there are about 8000 m³/d (50,000 b/d) of Alberta light oil production shut in, Minion feels the real reason for the light oil marketing problems not being worse is that Syncrude and Suncor oilsands plants have been producing at sharply reduced capacity because of technical problems.

Overall, this situation is similar to that in the heavy crude oil market, where producers in Saskatchewan and Alberta have already experienced domestic heavy crude oil being pushed out of the market by heavy oil imported from offshore suppliers by Central and Eastern Canadian refineries.

International sources expect that the market will bottom out at between U.S. \$28 and U.S. \$32, down from the current U.S. \$34, which is the market price for Saudi light oil.

Overall, the current international oil market scene has the effect of retarding the consumption of Canadian oils - light as well as heavy - because of the availability of equal grades of oil at lower cost on the world oil spot market. The incentive for Canadian energy companies to develop alternative crude oil sources like heavy oil upgraders, oil sands based plants, or even coal conversion plants, while their conventional crude oil resources are partially shut in, is, of course, non-existent.

While this situation should be considered an interim phenomena, it results in a significant delay in development of such energy projects.

9.5 INDUSTRY VIEW OF DEMAND UNDER RECENT DEVELOPMENTS

While it is recognized that the looming international oil glut may have short term benefits to the consumers in the industrialized countries, it is recognized that in the medium term, the situation could result in a very serious shortage. If investment into alternatives to Middle East oil are delayed as long as the glut actually lasts, the industrialized countries will find themselves again in a situation experienced during the 1970's, when OPEC commanded sudden price jumps which brought several countries to the brink of bankruptcy.

The recent events surrounding the Alsands Project have increased the level of uncertainty under which many other energy projects are currently suffering. While the commercial terms decided by the respective governments could simply be changed if so desired, the currently low level of competitiveness of Western Canadian light and heavy crude oils could be corrected only by the Federal Government via modernization of the Oil Import Compensation Program. Additional major problems resulting in increased uncertainty includes the inflation rate and the development of the interest rate.

In his address of the Canadian Club of Montreal, William Wilder, President of Hiram Walker Resources Ltd., of Toronto, early this month, discussed the major problems surrounding the planned energy projects in this Country: "Few, if any, of the major investment projects such as Alsands, Cold Lake, the Alaska Pipeline

and the Arctic Islands and the East Coast Offshore developments now make economic sense because of the combination of the world oil glut and reduced returns available under the NEP and the Ottawa/Edmonton Pricing Agreements". Using the example of Suncor, Inc., the country's first oil sands plant, Wilder identified the difficult situation for investors that are faced with the continuing on/off policy by the regulatory authorities (Globe & Mail, March 2, 1982).

While it is gradually getting more expensive to import heavy oil, Venezuelan heavy oil still cost Canadian refineries less than half that of equivalent quality Canadian oil over a year ago, and the price discounts for buying Venezuelan oil currently are only 20-30%. Canadian refiners in Central and Eastern Canada can still not afford to buy Canadian heavy crude oil and so - because of the subsidies under the Petroleum Import Compensation Program - cause the Canadian heavy oil producers to lose valuable market share.

The Independent Petroleum Association of Canada (IPAC) has urged the Federal Government to remodel its Petroleum Import Compensation Program. IPAC claims that refiners import foreign heavy crude oil at about \$9 to \$12 per barrel less than comparable quality Canadian crude would cost. In addition to the somewhat outmoded subsidy levels, the quality adjustments for Canadian heavy crude oil are very narrow, while other oil producing countries allow for larger cost reduction to compensate for lower quality.

10. FORECAST OF INTERNATIONAL PROJECTS

10.1 UNITED STATES OF AMERICA

It is widely held that the trend to lower quality transportation fuels, e.g., lower cetane numbers for road transportation diesel fuels, is an international phenomenon. At the same time, the availability of heavy oil - mainly from refinery resids - is increasing. It is for this reason then, that most industrial countries are developing projects specifically geared to make use of these heavy stocks via upgrading processes to produce as much lighter product as possible.

The main countries actively pursuing these routes are the U.S., Japan and several of the European countries.

A total of 26 resid upgrading projects have been announced in the U.S., many using the process routes of hydro-desulphurization and coking or cat cracking as well as hydro-conversion and some solvent extraction. While, for comparison, Canada's oils have relatively low sulphur content, the U.S. crude slate is expected to become heavier and higher in sulphur content. About 105,000 m³/d (650,000 b/d) of resid are slated for processing in the plants or committed projects in the U.S. alone (Oil & Gas Journal, January 5, 1981).

In the area of coal conversion, in a study by the National Coal Association in 1980, 41 facilities were identified being in operation - 18 liquefaction and

23 gasification plants. Six of these synfuel facilities were found under construction, two of which involve liquefaction and four gasification. An additional total of 42 facilities had been proposed and were in the planning stage, 16 of which were classified as liquefaction and 26 as gasification. The only commercial facilities in operation were five small low Btu gasification plants producing fuel gases. No commercial liquefaction, high Btu or medium Btu gasification facilities were in operation then. Three commercial synfuel facilities were under construction - one by Tennessee Eastman and two low Btu gasification plants for industrial fuel (National Coal Association, 1980).

The fate of coal synthetic fuel projects in the U.S. has, in the past four years, been pegged to the generation and modification of the U.S. Synthetic Fuels Corporation, initially planned during the Carter Administration. Having experienced complete changeover of executive personnel, the agency is only lately finding success in contracting out significant developing synfuel projects.

Early in February, the President gave the go-ahead to the U.S. Synthetic Fuels Corporation to start providing loan guarantees and other financial assistance for specific projects. The Corporation has the authority to commit more than \$14 billion U.S. in the next two years (The Wall Street Journal, 1982). While this level of funding is expected to spur some commercial development, it had to reduce the number of funding-worthy projects to eleven. Of these, eight projects will use coal as feedstock, while the others will use oil shale, peat or heavy oil. It is expected that SFC will reduce the eleven projects further in order to provide larger funding to the more fund-worthy projects.

The eleven projects still under consideration by SFC for financial aid are as follows:

Northern Alabama - North Alabama Coal Gasification Consortium (including Santa Fe International, Kidder Peabody, and Air Products & Chemicals), Murphy Hill, Ala., coal 1910 m³/d (12,000 b/d) oil equivalent, loan guarantee.

Calsyn - California Synfuels Research Corp., West Pittsburgh, Calif., heavy oil, 812 m³/d (5,100 b/d), loan guarantee.

Cool Water - Texaco Inc., Southern California Edison Co., Electric Power Research Institute, Bechtel Power Corp., General Electric Co., Empire State Electric Energy Research Co., and JCWP (a consortium of Japanese companies),

Daggett, Calif., coal gasification combined cycle test
385 m³/d (4,300 b/d) oil equivalent, price guarantee.

Breckenridge - Ashland Synthetic Fuels Inc. and
Bechtel Petroleum Inc., Breckenridge Country, Ky.,
coal - 7930 m³/d (49,800 b/d) oil equivalent, loan
guarantee.

Coal Liquid - Coal Liquid Inc., Shelbyville, Ky.,
coal and oil - 160 m³/d (1,000 b/d); price guarantee
and purchase commitment.

First Colony - Peat Methanol Association, Cresswell,
N.C., peat 303 m³/d (1,900 b/d) oil equivalent, loan
guarantee and price guarantee.

MLGW - Memphis Light, Gas & Water (City of Memphis),
Memphis, Tenn., coal 1346 m³/d (8,400 b/d) oil equiv-
alent, price guarantee and loan guarantee.

TSA - Tennessee Synfuels Association (joint venture
of Koppers Synfuels Corp. and Citgo Synfuels Inc.),
Oak Ridge, Tenn., coal - 7962 m³/d (50,000 b/d) oil
equivalent, price guarantee and loan guarantee.

Paraho - Paraho Development Corp., Uintah County,
Utah, oil shale 4777 m³/d (30,000 b/d) loan and
price guarantee.

Hampshire - Hampshire Energy (joint venture of Kaneb
Services Inc., Koppers Co. Inc., Northwestern Mutual
Life Insurance Co., Metropolitan Life Insurance
Co., and Sohio, which is not requesting SFC aid),

Gillette, Wyo., coal 3488 m³/d (19,377 b/d of gasoline, 914 b/d of LPG and 1618 b/d of mixed butanes), price guarantee and loan guarantee.

WyCoal - Wycoal Inc. (a Panhandle Eastern Company) and Ruhrgas Carbon Conversion Inc., near Douglas in Converse County, Wyo., coal - 4300 m³/d (27,000 b/d) oil equivalent, loan guarantee and price guarantee.

The major projects currently in operation in the U.S. include the Exxon Donor Solvent Process demonstrated by Exxon Research & Engineering Company in a 250 t/d pilot plant at Baytown, Texas.

Ashland Synthetic Fuels Inc., and Hydrocarbon Research, Inc., (HRI) have operated for over a year a 600 t/d coal liquefaction plant based on the H-Coal process of HRI. The plant is located at Catlettsburg, Kentucky.

Tristate Synfuels Company is planning a coal liquefaction plant near Henderson, Kentucky. Initially it was planned to use the Fischer-Tropsch technology (as used by Sasol in South Africa), but a recent switch to coal-to-methanol-to-gasoline was made because of changed market conditions.

The Solvent Refined Coal processes (SRC-I and SRC-II) have reached status ready for demonstration. While SRC-I project is continued by International Coal Refining in Newman, Kentucky, the SRC-II development by Gulf and its consortium was halted during 1981.

Various gasification processes are being developed in the U.S., currently, the Texaco gasification process is operated in Texaco's pilot facilities and one at Tennessee Valley Authority (in an ammonia fertilizer plant), but commercial plants are only in the planning stage - W.R. Grace project at Basket; Kentucky to employ the Mobil-M process; Tennessee Eastman for an acetic acid production plant; and, a Southern California Edison Combined Cycle plant in Barstow, California.

With the recent authorization of the U.S. Synthetic Fuels Corporation to now actively support the development of a synthetic fuels industry in the U.S., a successive and continuing development and construction of demonstration plants followed by a few commercial size oil shale/coal conversion plants can be expected.

10.2 JAPAN

Japan had established its Sunshine Project in 1973-74 with the goal of identifying and developing to commercial use, as many alternative energy sources as the country could develop. In his luncheon address to the annual meeting of the Canadian Coal Association on September 22, 1981, Mr. Hiraiwa, the President of the Tokyo Electric Power Company, identified several pilot plants, demonstration plants and early commercial plants for the three liquefaction routes of solvolysis, solvent extraction and direct hydrogenation. These plants would include several pilot plants up to a capacity of 250 t/d liquid fuel output constructed and operated until the end of 1983, and followed by 1 300 t/d demonstration plant beginning operation in 1985 with a 25,000 t/d demonstration plant following during that year, and a third 25,000 t/d demonstration plant to operate between 1988 and 1989. The first of the plants for 300 t/d commercial plants would begin operation in 1988, while the first 25,000 t/d commercial coal liquefaction plants would start operating at about 1989 (Hiraiwa, 1981).

It is the Japanese intention to continue building commercial coal liquefaction plants to suit demand.

Following several pilot and demonstration plants of up to 1,000 t/d capacity, the Japanese plan for coal gasification identifies the first 1,000 t/d commercial plant to begin operation in 1987.

10.3 EUROPE

The two major countries developing coal conversion systems are West Germany and the U.K. Shell in the Netherlands and various developers in the German Democratic Republic are also active.

The British developments are carried out by the National Coal Board, including two liquefaction process routes and one gasification route by the British Gas Corp., on the BGC/Lurgi slagging gasifier.

During 1981, the Coal Board's plans included the construction of two 25 t/d pilot plants. Its commercialization plan was geared to the first large scale facility not before the year 2000 if built in the U.K., but earlier if desired and funded by foreign sponsors.

The BGC-Lurgi gasifier developed by British Gas Corporation has been demonstrated with a large variety of international coals showing very attractive results and being therefore considered by many gasification route evaluators as a contender for early gasification projects.

The U.K. however, because of its relatively large reserves in indigenous oil and gas is not seen as a major market for synthetic fuels production.

In West Germany, the Federal and several State Governments had begun funding for further development of

the domestic coal conversion technology of pre-war and wartimes in 1973, when the need arose for alternatives to the import of conventional crude oil. Subsequently, funding was established to the extent that the current program in the Country includes eight pilot plants for coal gasification in operation or under construction and two demonstration plants of 200 t/d and 6 t/d capacity for coal liquefaction, both of which have been operating since 1981.

The commercial projects plan involved eleven coal gasification and three liquefaction projects, most of which were slated for start-up between 1984 and 1987. However, recent economic difficulties have curtailed the available funding for commercial project development. It is expected, therefore, that while Western Germany, due to its large dependence on energy imports, will need to develop its synthetic fuel industry based primarily on coal, the active installation of some or all of the plant projects will be considerably delayed into the late 1980's or early 1990's (Specks, 1981).

11. DEMAND ANALYSIS FOR THICK WALL PRESSURE VESSELS IN CANADA

11.1 LIKELY CANADIAN ENERGY PROJECTS

The uncertainties currently surrounding the energy scenarios in Canada as well as internationally have been described in earlier sections and, while forecasting of demand for a given product or service under such described circumstances is a rather subjective affair, for the purpose of this project the parameters established in the Section 9.2, Canadian Energy Demand Forecast, will be used as guidelines. In addition, the projects likely to proceed to implementation will be analyzed to estimate when they could become available for start-up and reading of plant capacity.

On a type-of-project basis, the following project development is forecast.

On Surface-Mined Oil Sands Plants - It is very likely that the Alsands Project will go ahead during 1982. Further, it is assumed that the Canstar project or a similar project will be developed and come on stream by 1991 or 1992. In addition, it is assumed that a third oilsands plant of about 23,885 m³/d (150,000 b/d) capacity will be built to produce by 1987. This includes also the Syncrude expansion by 1987.

The In-Situ Oil Sands Projects are difficult to assess. Given an economic situation of reasonable certainty as forecasted, the Esso Cold Lake pro-

ject (including a group of Canadian sponsors) will eventually proceed. This, however, is not foreseen to be completed before 1992; it may then start-up gradually to reach full capacity after four years. The smaller size plants will unlikely require stand-alone upgrading capacity, because the then existing refineries would accommodate their output.

On Heavy Oil Upgraders - Both the Carmont and Husky projects are seen to go ahead with little delay, and, for the purpose of this survey, an additional capacity of about $23,885 \text{ m}^3/\text{d}$ (150,000 b/d) over the forecast period will come on stream. Husky's schedule per submission to the Saskatchewan Government on March 4, 1982 is too optimistic by one year. Ultramar, being already committed, will be first off by 1985. Petro-sar could come on stream by 1989.

On Coal Conversion - One direct or indirect coal liquefaction plant of demonstration size of between $1592 \text{ m}^3/\text{d}$ and $3185 \text{ m}^3/\text{d}$ (10,000 b/d and 20,000 b/d) is seen to be operational by 1990, followed by two commercial scale plants in 1996 and 2000. These commercial plants will be developed for different marketing reasons. A single product plant, using direct liquefaction, and a plant of products variation capability of varying ratio of gasoline and diesel fuel, using indirect coal liquefaction. The latter plant may employ several processing routes, but will in any case require the gasification of coal for synthesis gas production.

It should be noted that regarding the type and amount of pressure vessels required, direct and indirect coal liquefaction differ substantially.

Chemical methanol is made currently from natural gas and will continue to be for at least a decade. While there is foreseen a large emerging demand for methanol as fuel for power stations and for transportation in the Pacific Rim countries and elsewhere, the timing of this demand is uncertain.

In Alberta, several projects are in the planning stage. The concept is to find a market for the currently abundant natural gas and a means of transportation for the coal. The railroad systems are operating at capacity now and will add little increase in the future. Therefore, pipelining is the only transportation option the resource industries have available.

Methanol would be used as carrier medium for comminuted coal in a slurry pipeline system. At a later date, when natural gas is not available or uneconomic, the coal can also be used as feedstock for methanol production.

If the methanol-from-coal scenario will ever occur, is unclear. If that is the case, however, the demand for pressure vessels will increase strongly because of the many gasifiers needed. This scenario therefore, is looked at separately and can be superimposed on the base case if desired.

On Hydrogen and Carbon Dioxide from Coal - Hydrogen plays a pivotal role in almost all crude oil, heavy oil and (direct) coal liquefaction projects. Large amounts of it are required for upgrading to transportation fuels, refinery or chemical feedstocks. Carbon dioxide is used in the U.S. for enhanced oil recovery projects. In Canada at this time, natural gas or natural gas liquids are used in miscible or immiscible flooding type enhanced oil recovery projects because of the high degree of availability at low cost. Given that carbon dioxide-from-coal (jointly produced with hydrogen) will become more economical, or that natural gas or natural gas liquids will at some time become unavailable as feedstock for hydrogen and for application in enhanced oil recovery by Government decree, such an option (Hydrogen/Carbon-Dioxide-from-Coal) could possibly become feasible. If so, the domestic demand for both gases will be large. It is assumed here that the demand for hydrogen and carbon dioxide from coal will become reality by 1993 and in intervals of five years.

A project calendar is contained in Table 11-1. It identifies the projects by capacity and start-up timing. Rated capacity is considered reached two years after start-up. The forecast projects are described in Appendix G.

Figures 11-1 through 11-4 show the increase of production capacity over the conventional crude oil supply

TABLE 11-1
PROJECT CALENDAR

	Capacity		Start-Up Year	Current Status
	MMbbl/d	(bbl/day)		
<u>HEAVY OIL UPGRADERS</u>				
ULTRAMAR	4777	39,000	1983	
PETRO CANADA	796	5,000	1986	Planned.
CARBONT (MONTREAL HEAVY FUEL OIL UPGRADE PROJECT)	7166	45,000	1986	Detail Planning. Process Selection.
HUSKY & CONSORTIUM	6370	40,000	1987	Process Selection. Project Decision subject to favour- able economics.
PETROSAR	7166	45,000	1989	Except for vacuum distill- ation unit, project suspended for economic reasons.
UNKNOWN	12740	80,000	Gradually to 2000	
<u>OIL SANDS - SURFACE MINED</u>				
SYNCRUDE EXPANSION	9554	60,000	1987	Planned.
ALSANDS	23885	150,000	1989	All approval OK. Undecided regarding economic issues.
CANSTAR (NOVA & PETRO CANADA)	25477	160,000	1991-92	Planned. Process Evaluation Application 1992 or 1993.
GULF (SANDALTA)	23885	150,000	1997	Planned.
SHELL. OR TENNECO + CDC	Mining Leases		2001-05	
<u>OIL SANDS - IN-SITU</u>				
COLD LAKE	25477	160,000	1992-96	On hold.
SHELL	796	5,000		
	to	to		
	3185	20,000		
PETRO CANADA	796	5,000		
	to	to		
	3185	20,000		
<u>COAL CONVERSION</u>				
COAL LIQUIDS DEMONSTRATION PLANT (MARITIMES OR WESTERN CANADA)	3185	20,000	1990	
COAL TO LIQUID FUELS (WESTERN CANADA)	9554	60,000	1996	
COAL TO LIQUID FUELS (WESTERN CANADA)	9554	60,000	2000	
<u>METHANOL PLANTS</u>				
	Capacity MMbbl/d			
PLANT A	2,000		1987	
PLANT B	2,000		1991	
PLANT C	2,000		1993	
PLANT D	2,000		1996	
PLANT E	2,000		1999	
<u>AMMONIA PLANTS</u>				
PLANT A	1,200		1988	
PLANT B	1,200		1994	
PLANT C	1,200		2000	
<u>HYDROGEN & CARBON DIOXIDE FROM COAL</u>				
	Capacity MMSCFD	$\text{Nm}^3/\text{d} \times 10^6$		
JOINT MANUFACTURING PLANT A	200	5.7		
	75	4.2	1993	
JOINT MANUFACTURING PLANT B	200	5.7		
	75	4.2	1998	

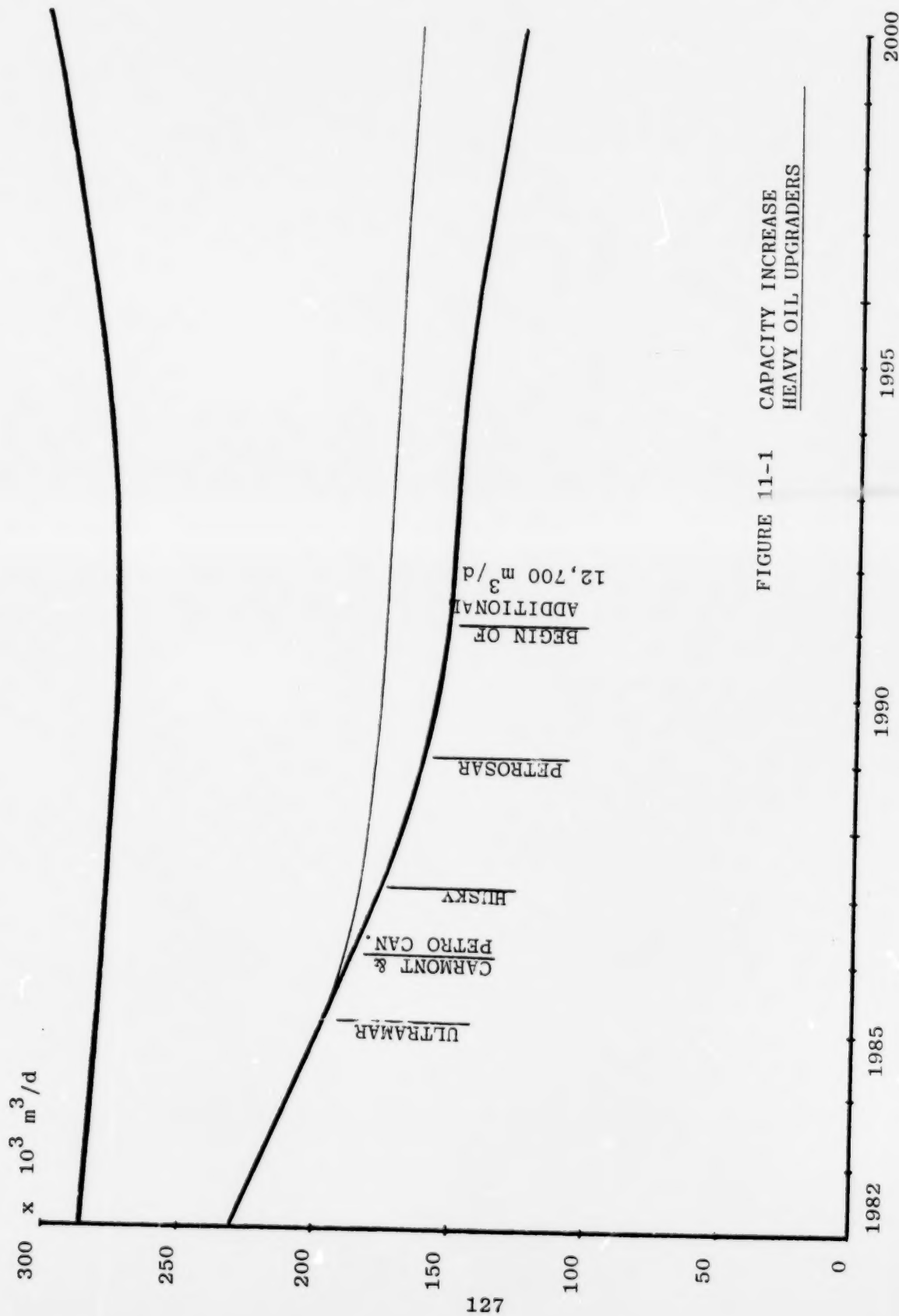
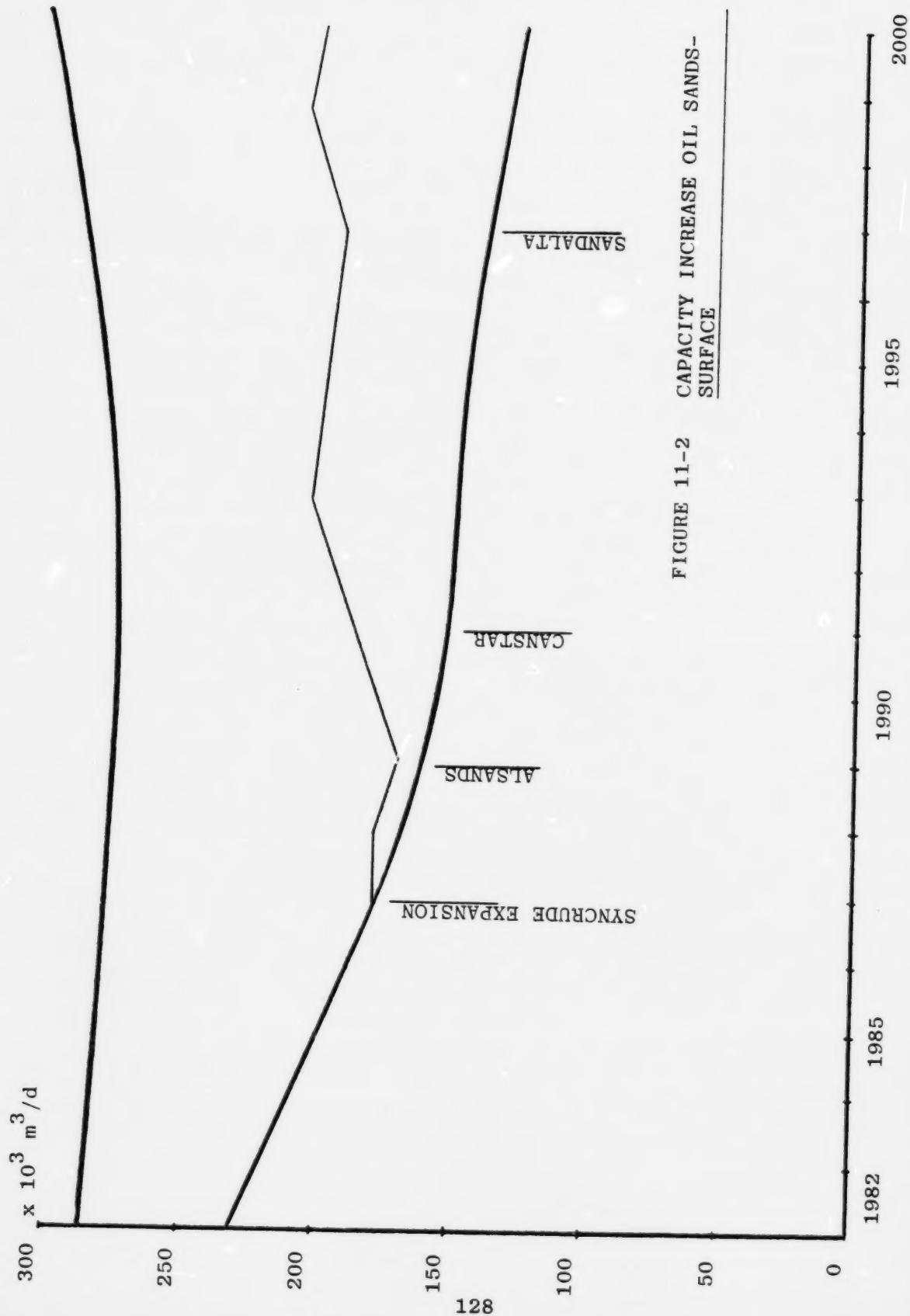


FIGURE 11-1 CAPACITY INCREASE
HEAVY OIL UPGRADERS



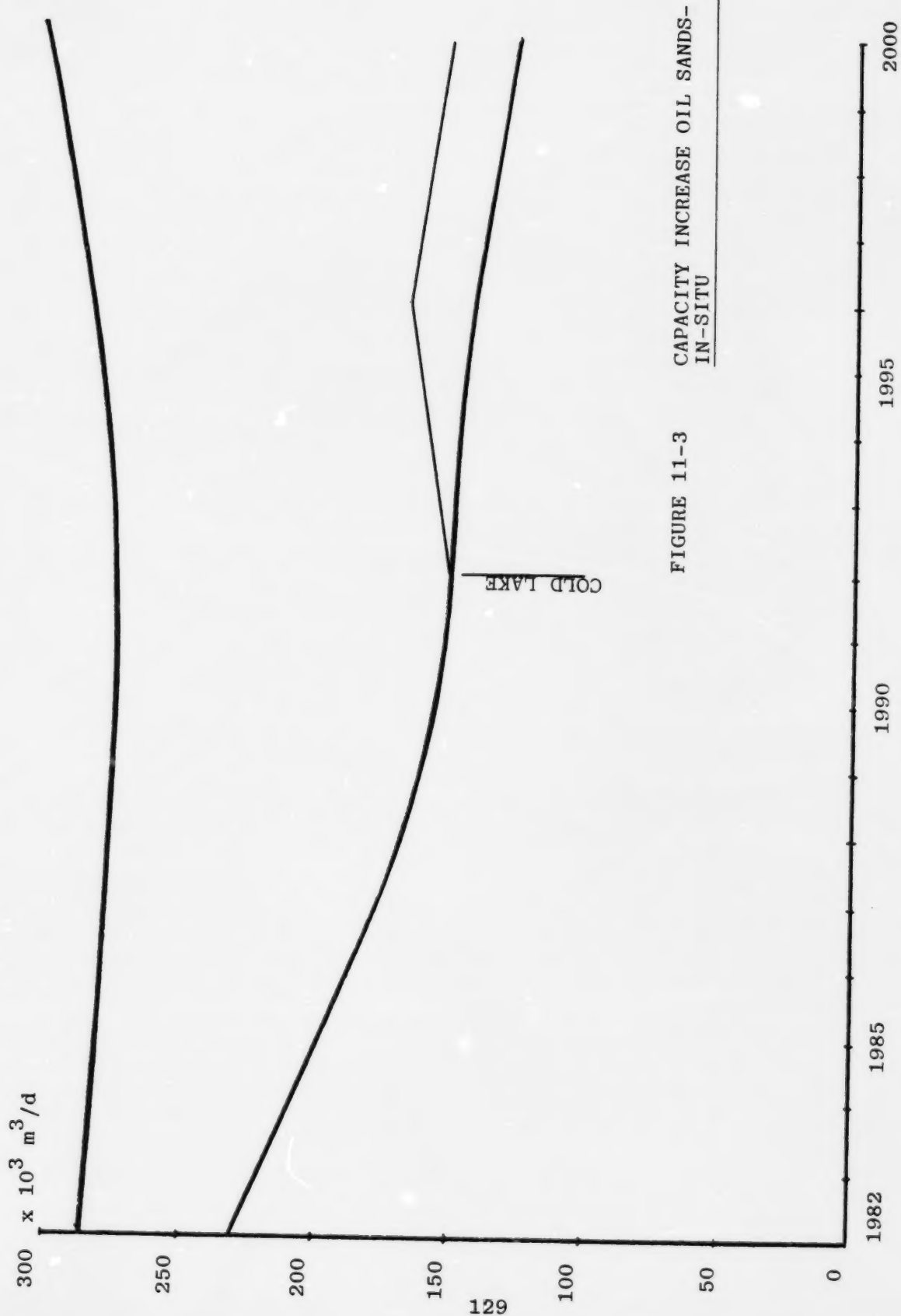


FIGURE 11-3 CAPACITY INCREASE OIL SANDS-
IN-SITU

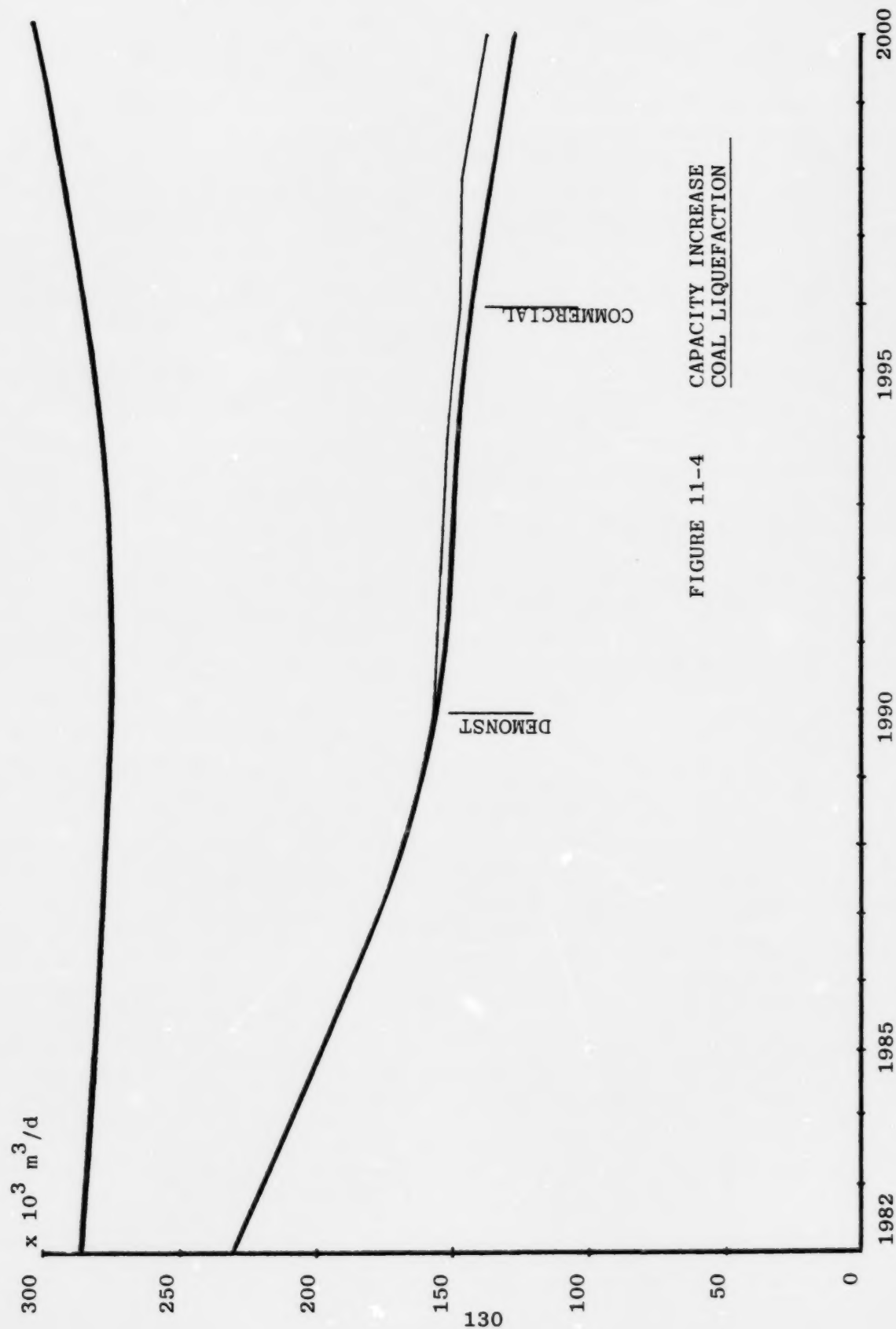


FIGURE 11-4

CAPACITY INCREASE
COAL LIQUEFACTION

for each of the major synthetic oil production options - heavy oil upgrading, surface-mined oil sands, in-situ oil sands and coal liquefaction.

Oil production from the Beaufort Sea and Arctic or from the East Coast or other frontier areas is not accounted for in detail in this forecast. Although some frontier produced oils may be considerably heavier than the typical Canadian light crude oil, their upgrading requirements are considered within the capabilities of conventional refineries.

Furthermore, such potential contributors to the "oil or equivalent" pool as methanol are not considered from a Canadian demand point of view, but rather as opportunities for export. Similarly, enhanced recovery of conventional oil is considered only as far as the requirement for CO₂-from-coal is concerned.

The summarized forecast of all the contributing oil production or equivalent options is shown in Figure 11.5.

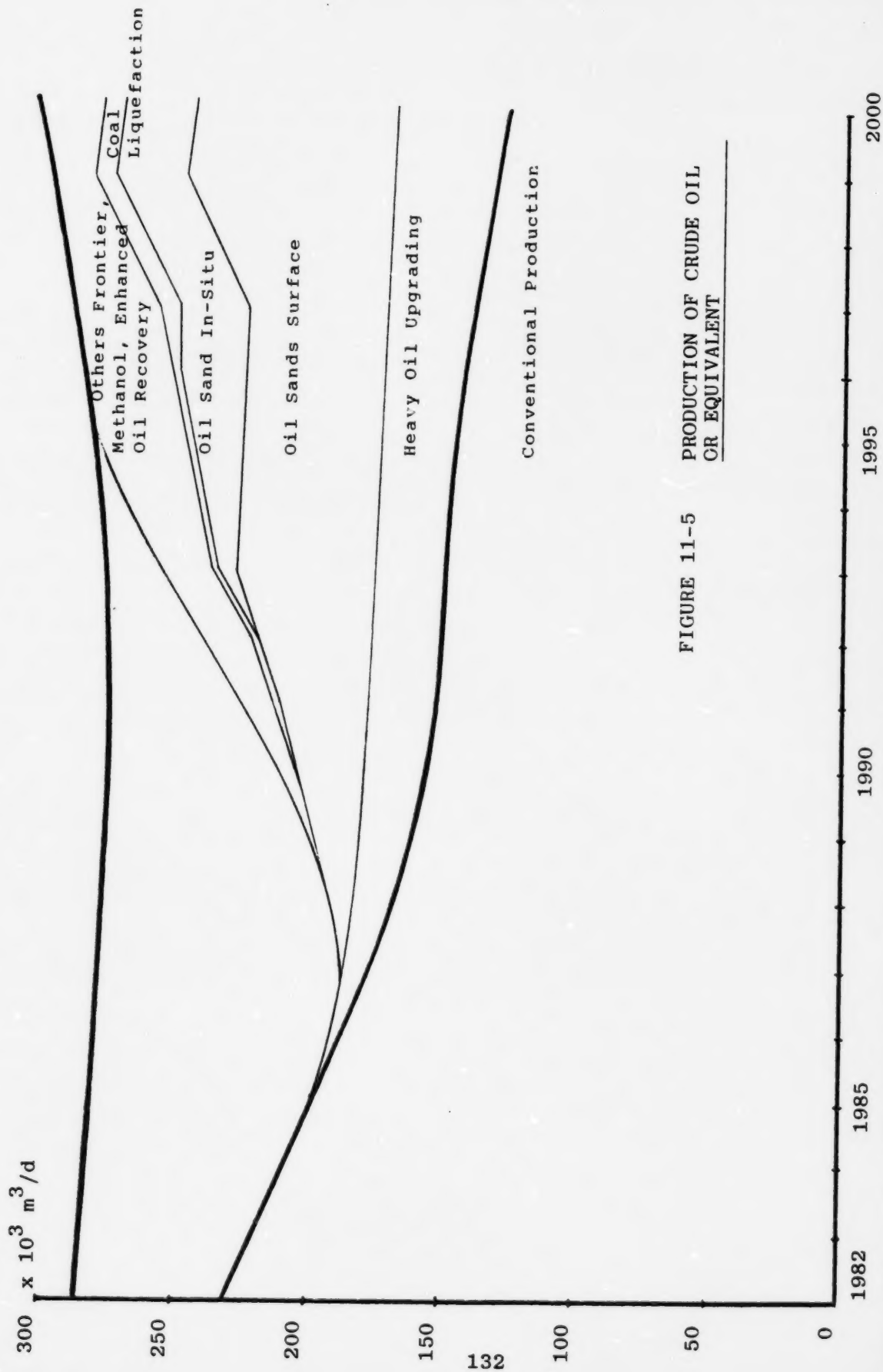


FIGURE 11-5 PRODUCTION OF CRUDE OIL OR EQUIVALENT

11.2 HEAVY WALL PRESSURE VESSEL DEMAND FOR TYPICAL PROJECTS

11.2.1 GENERAL

In the following subsections, the type and number of pressure vessels typical to the various project categories are identified for a representative project capacity. All of these vessels of course share the common features as per the definition of pressure vessel in this study.

11.2.2 OIL SANDS

The 22,292 m³/d (140,000 b/d) Alsands Plant will contain the following pressure vessels:

- 2 - Naphtha Hydrotreaters;
- 2 - Kerosene Hydrotreaters;
- 2 - Gas Oil Hydrotreaters;
- 3 - Gasifiers;
- 4 - Vessels Associated with the Gasifiers;
- 13 - TOTAL

After the Alsands project, all oil sands upgraders are expected to be based on the hydrogen addition processing routes. This includes Canstar, Cold Lake and any other upgrading project larger than 6370 m³/d (40,000 b/d).

11.2.3 HEAVY OIL UPGRADING

A typical upgrading operation like Husky Oil's Plains project will contain the following type and numbers of heavy wall pressure vessels when built for a capacity of $6370 \text{ m}^3/\text{d}$ (40,000 b/d):

- 4 - Reactors;
- 4 - Separators;
- 4 - Catalyst Addition/Withdrawal Vessels;
- 2 - Pressure Let Down Drums;
- 2 - Naphtha Hydrotreaters;
- 2 - Gas Oil Hydrotreaters;
- 2 - Gasifiers;
- 3 - Gasifier Associated Vessels;
- 23 - TOTAL

11.2.4 COAL LIQUEFACTION

11.2.4.1 DIRECT COAL LIQUEFACTION BY HYDROGENATION

A typical $9554 \text{ m}^3/\text{d}$ (60,000 b/d) direct coal liquefaction plant using direct hydrogenation will contain the following vessels:

- 12 - Liquefaction Reactors;
- 8 - Hot Separators;
- 6 - Cold Separators;
- 4 - Wash Towers;
- 6 - Lock Pots;
- 3 - Pressure Let Down Drums;
- 2 - Hydrotreaters;
- 41 - TOTAL

In addition, if hydrogen is produced from liquefaction resids, a gasification system containing the following will be required:

- 2 - Gasifiers;
- 3 - Associated Vessels;
- 46 - GRAND TOTAL

11.2.4.2 INDIRECT COAL LIQUEFACTION BY FISCHER-TROPSCH

A typical 7962 m³/d (50,000 b/d) indirect coal liquefaction project via Fischer-Tropsch (i.e., as in South Africa) will contain heavy wall pressure vessels as follows:

- 25 - Gasifiers;
- 45 - Vessels Associated with Gasification;
- 9 - F-T Synthesis Columns;
- 79 - TOTAL

11.2.5 CO₂ AND H₂ FOR ENHANCED OIL RECOVERY AND UPGRADING

To produce carbon dioxide and hydrogen from coal at 5.7 x 10⁶ Nm³/d, H₂ (200 MMSCFD) and 4.2 x 10⁶ Nm³/d, CO₂ (150 MMSCFD), a plant will need:

- 9 - Gasifiers;
- 10 - Associated Vessels;
- 19 - TOTAL.

11.2.6 METHANOL AND AMMONIA SYNTHESIS

A 2000 t/d methanol plant using natural gas as feedstock requires:

1 - Synthesis Reactor.

If coal is used as feedstock for the synthesis gas an additional:

4 - Gasifiers;

5 - Associated Vessels

10 - TOTAL

A 1000 t/d ammonia plant using natural gas as feedstock requires:

1 - Synthesis Reactor.

If coal is used as feedstock for the synthesis gas an additional:

2 - Gasifiers;

3 - Associated Vessels

6 - TOTAL

Table 11-2 summarizes the thick wall pressure vessel requirements for the typical energy projects.

11.3 BASE CASE OF DEMAND FORECAST

For the timing of procurement of heavy wall pressure vessels, a three-year period prior to plant start-up is assumed. Consequently, the vessel demand for the anticipated projects comes into effect three years earlier. Following then is the Calendar for Orders of Heavy Pressure Vessels - Table 11-3.

TABLE 11-2
THICK WALL PRESSURE VESSELS FOR TYPICAL ENERGY PROJECTS

PROJECT CATEGORY	CAPACITY	PRIMARY CONVERSION		SECONDARY UPGRADING			GASIFIERS & OTHERS	TOTAL PRESSURE VESSELS
		REACTOR	OTHERS, eg SEPARATORS	NAPHTHA	DISTIL-LATE	GAS OIL		
OIL SANDS (e.g., ALSANDS)	22,292 m ³ /d (140,000 b/d)			2	2	2	3+4	13
HEAVY OIL UPGRADING	6,370 m ³ /d (40,000 b/d)	4	4+4+2	2		2	2+3	23
COAL LIQUEFACTION DIRECT	9,554 m ³ /d (60,000 b/d)	12	8+6+4 +6+3		2		2+3	46
COAL LIQUEFACTION INDIRECT	7,962 m ³ /d (50,000 b/d)						25+45+9	79
CO ₂ FOR EOR	2.1 Nm ³ /d (75 MMSCFD)						9+10	19
H ₂ FOR UPGRADING	5.7 Nm ³ /d (200 MMSCFD)							
METHANOL	2,000 t/d		1 Synthesis					1
AMMONIA	1,000 t/d		1 Synthesis					1

TABLE 11-3 - FORECAST OF PRESSURE VESSEL ORDERS

1983	18	Ultramar	
	26	Carmont	
	4	Petro Canada	
1984	23	Husky	
	3	Syncrude Expansion	
	1	Methanol	
1985	1	Ammonia	
			1983-85
			<u>SUBTOTAL:- 76</u>
1986	13	Alsands	
	26	Petrosar	
1987	20	Coal Liquids Demonstration	
1988	1	Methanol	
	15	Canstar	
1989	46	Cold Lake	
1990	19	CO ₂ and H ₂	
			1986-90
			SUBTOTAL:- 140
			<u>CUMMULATIVE:- 216</u>
1991	46	Cold Lake	
	1	Methanol	
	1	Ammonia	
1992	23	Additional 6370 m ³ /d (40,000 b/d) heavy oil upgrading capacity	
1993	79	Coal Liquids (F-T)	
	1	Methanol	
1994	92	Sandalta (or similar)	
1995	19	CO ₂ and H ₂	
			1991-95
			SUBTOTAL:- 262
			<u>CUMMULATIVE:- 478</u>
1996	1	Methanol	
	23	Additional 63070 m ³ /d (40,000 b/d) heavy oil upgrading capacity	
1997	46	Coal Liquids (direct)	
	1	Ammonia	
1998/9	92	23,885 m ³ /d (150,000 b/d) oil sands plant built in 2001-2003	
			1996-2000
			SUBTOTAL:- 163
			<u>CUMMULATIVE:- 641</u>

A total of about 640 heavy pressure vessels will be required by the year 2000. The estimated breakdown by weight and wall thickness range is

90 of 500 plus tonnes and 250-300mm (10-12")
 140 of 200-500 tonnes and 150-250mm (6-10")
 150 of Below 200 tonnes and 100-150mm (4-6")
 260 of Below 200 tonnes and 63-100mm (2.5-4")

11.4 PESSIMISTIC AND OPTIMISTIC CASES

A pessimistic scenario is envisaged to develop if these two events occur:

- the Government of Canada continue the NEP program without substantial improvements for incentives to invest in oil sands or upgrading projects and without rectifying the Oil Import Compensation Program; and,
- the Hibernia oil field offshore Newfoundland being rapidly developed for producing 31,850 m³/d (200,000 b/d) by 1986 and an additional similar amount by about 1989.

This would result in the cancellation of several of the early projects and a further delay of most of the remaining projects. These projects surviving to fruition would be those representing either an expansion of existing facilities, or a disposal necessity, or a need for security of supply.

The relevant level of demand for heavy wall pressure vessels would be about 175, represented by the following projects:

- Petro Canada (1983);
- Syncrude Expansion (1984);
- Petrosar (1986);
- Additional 6370 m³/d (40,000 b/d) heavy oil upgrading capacity (1992);

- Additional 6370 m³/d (40,000 b/d) heavy oil upgrading capacity (1996); and,
- New 23,885 m³/d (150,000 b/d) oil sands plant (1998/9).

Should this scenario be additionally burdened with a drop of the world oil price to around \$25.00 (US) and remain at such a low level, the demand for heavy wall pressure vessels in Canada would likely be reduced to insignificance.

An optimistic scenario, however, could evolve from largely increased government incentives, from a strongly increasing world oil price (not later than 1983) and from a delay of offshore oil production to beyond 1990. This would cause construction of projects adding (to the base case) a production of about 50,000 m³/d (377,000 b/d), or about 200 to 250 heavy wall pressure vessels for a total of 840 to 890.

12. CANADIAN SUPPLY CAPABILITY NOW AND IN THE FUTURE

12.1 STEEL MAKING AND MATERIAL PROPERTIES

12.1.1 CURRENT STEELMAKING CAPABILITY

Both Canadian steel plate makers are currently neither producing any relevant alloy steels, nor any plate thicker than 100 mm. There is no measurable demand at this time for pressure vessels as per definition of this study in Canada.

On the few occasions in the past when alloy plate or very thick plate was required, the steel was imported.

While one of the steel companies has an excellent record in providing non-alloyed and light alloy line pipe steels of high quality and in large quantities, its operation is mainly geared to carbon steel products.

The other steel maker produces a wider range of products including normalized quenched and tempered plate of up to 3900 mm width and 100 mm thickness.

12.1.2 FUTURE STEEL MATERIALS REQUIREMENTS

In the short and medium term, no new steels are expected to become available that would be more cost effective than the currently proposed/used light alloys. Attempts to improve these steels are continuing, however, particularly in Japan, where the optimization to balance these steels for given applications is being intensely re-searched.

Clad plate offers an alternative of optimizing the balance of chemical/physical requirements to that of the stress bearing functions and also of fabrication. However, this still requires more development in Canada for very thick sections and various material combinations.

For shell designs with internal insulation, it is likely that refractory installation methods will be developed, resulting in increased reliability and ease of applications, e.g., automated field applied liquid material spin-on methods.

Concrete as pressure vessel construction material poses a danger because it could, in the long term, replace some of the pressure vessel steels. Concrete is further discussed in subsection 12.1.3.

Ceramics applied to the inside of the vessel would offer a low cost corrosion and abrasion resistant lining material. Major development work would need to be expended, particularly regarding the different (from steel) thermal expansion coefficient and the connection to nozzles and other penetrations through the shell.

The material question is to be considered jointly with the vessel design. If, for example, layered construction should gain ground, the currently available light alloys of medium plate thickness would likely suffice in the future; with the steels still being imported. Here, an intensive comparison of vessel designs, materials, fabrication capability and acceptability of various designs by project owners should be undertaken.

12.1.3 CONCRETE AS FUTURE COMPETITOR OF STEEL

The purpose of this subsection is to identify through brief descriptions of the state of the art and current developmental activities, as well as the current and future concrete material properties and construction techniques, as to what extent concrete as a potentially major future pressure vessel construction material might compete with steel.

Prestressed concrete vessels have been used to date widely for low and medium pressure containment, primarily in water and nuclear services.

An additional purpose of this subsection is to make the steel based pressure vessel fabricating industry aware of the potential competition arising from the concrete.

Two major techniques are discussed in the following- the applied pre-stressing method by wire winding by Taylor Woodrow, Southall, U.K., for the British Nuclear Industry and the concept developed and evaluated on behalf of the U.S. Department of Energy by T.Y. Lin International, jointly with Ralph M. Parsons Company.

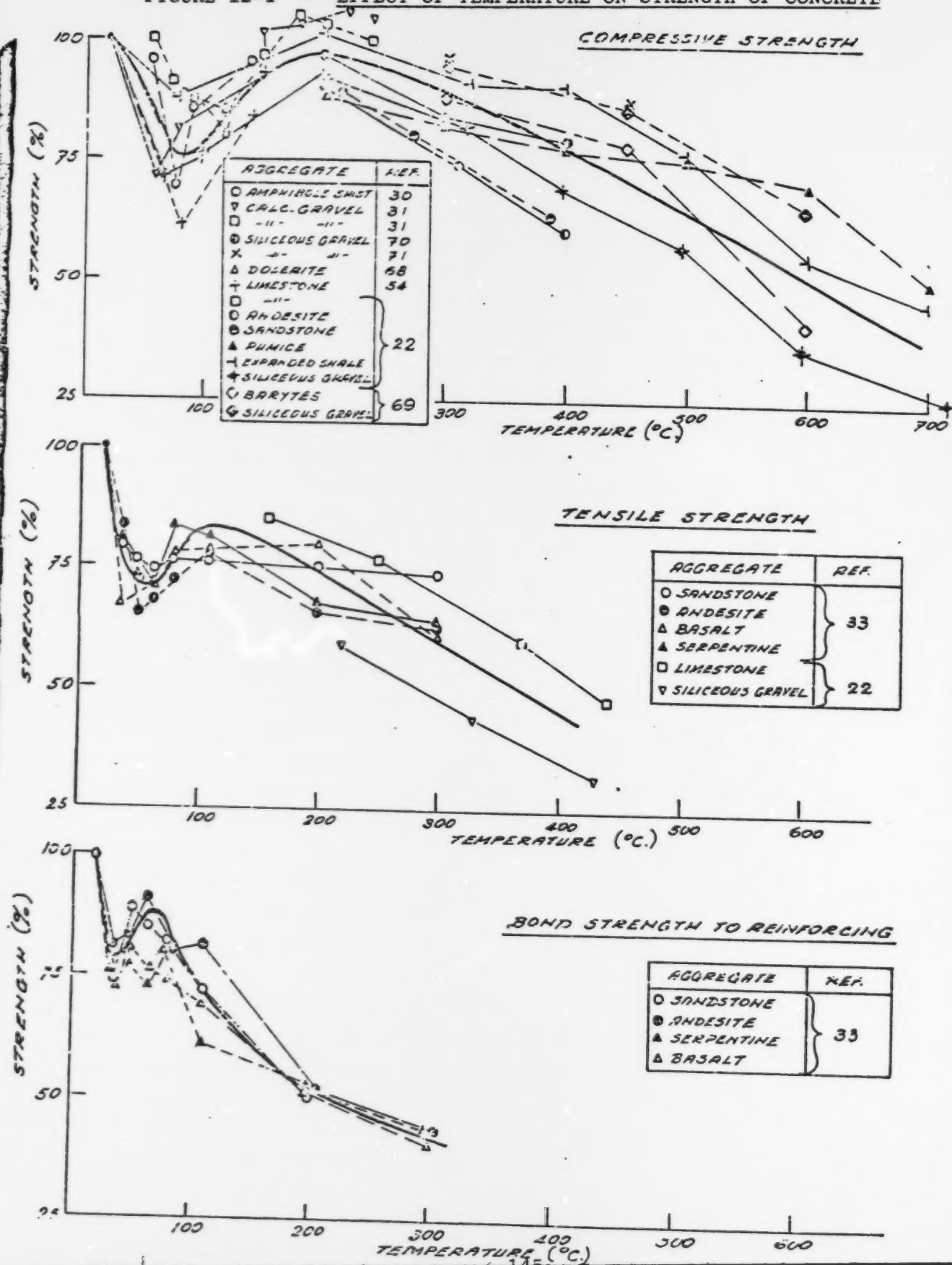
Several of the U.K. atomic reactors employ the multi-vessel concept, whereby several high pressure containers are embodied in one large block of reinforced and pre-stressed concrete.

While it is not possible to state in simple terms the maximum operating temperature concrete can stand, the effect of high temperature on conventional concrete depends, amongst other things, upon the type of aggregate used (Figure 12-1) and the ease with which the concrete can dry (dry concrete being better than moist concrete). Typical reductions in compressive strength are as follows for concrete which dries under the action of temperature:

<u>Aggregate</u>	100	300	500	700
Limestone	40	40	50	80
Silicious Gravel	15	10	25	50
Dolomite	25	15	35	65

Values are % reduction related to 20°C strength.

FIGURE 12-1 - EFFECT OF TEMPERATURE ON STRENGTH OF CONCRETE



As a result of drying at high temperature, both creep and shrinkage will increase significantly. By heating to temperatures in excess of 400°C , the thermal conductivity will be approximately halved, thereby increasing thermal gradients.

Work at Taylor Woodrow Research Laboratory shows that the effect of temperature is influenced by mix type, heating regime and moisture content. It is essential that if values for use in design are required that the specific concrete be tested after exposure to the temperature condition likely in practice.

One of the principal constraints of exposing the vessel concrete to high temperatures is the high levels of tensile stress generated in the coolest regions of the structure which have to be counteracted by the prestress. However, viable solutions have been achieved for nuclear containment structures where inner surface concrete temperatures of 75°C are sustained. Schemes have also been examined, combining special concretes and insulation to contain significantly higher temperatures. Based on prior experience, Taylor Woodrow feels that a pressure of 14 MPa could be contained in a 4.5 m diameter by 30 m high vessel, possibly with a wall thickness of 3-4.5 m.

Taylor Woodrow's wire winding technique of prestressing concrete is excerpted from Brunton (--).

The principle of winding wire around cylindrical structures to resist internal pressure has been

known since its application to large naval gun barrels in the nineteenth century, and the process is extensively used for the prestressing of circular reservoirs and tanks. The advent of prestressed concrete pressure vessels to contain the gas cooled reactors of nuclear power stations, requiring high densities of circumferential prestress, has again enabled use to be made of this very efficient method of prestressing.

The advantages of using wire winding as compared to alternative methods of circumferential prestressing for nuclear or other large pressure vessels are well understood but briefly, the major ones are as follows:

- a) High intensities of prestress in a very compact arrangement.
- b) No friction losses.
- c) No expensive anchorage components.
- d) Smooth outer surface of pressure vessel with no heavy anchorage ribs.
- e) Less congestion of prestressing ducts in the walls of the concrete vessel.
- f) Higher quality tendon with no crossing wires resulting in improved ultimate load and strain capacity.
- g) Lower costs.

The wire winding system, which has been covered by various patents throughout the world, is based upon the use of concentrated bands of 5.08mm (0.2") diameter high-tensile steel wire with low relaxation wound under tension into channels preformed in the vessel wall. The number, width and spacing of

bands and number of layers of wire applied, can be varied widely to suit the particular requirements of the design.

For the Hartlepool and Heysham pressure vessels the circumferential channels are formed in a series of 24 precast units 381mm (15") overall thickness which form the permanent formwork during construction. The channels are 612mm (24.12") wide and 228mm (9") deep and lined with a 3.2mm (1/8") sheet steel continuous membrane to prevent the ingress of moisture. Each of the 20 vessel tendon bands has an ultimate tensile strength in excess of 13,800 tonnes (see Figure 12-2).

To enable the winding machine to be readily handled on site, it is formed by two vehicles which are rigidly bolted together. It is carried on a steel platform which can be rapidly raised or lowered to any position on the vessel by six automatically controlled long stroke hydraulic rams, which ensure that the platform remains level during these operations. During winding, the platform is locked to the vessel and to the twelve supporting columns. Two machines with their associated platforms are used and work independently of one another. However, more machines can be used if required by the program.

FIGURE 12-2

Hartlepool and Heysham

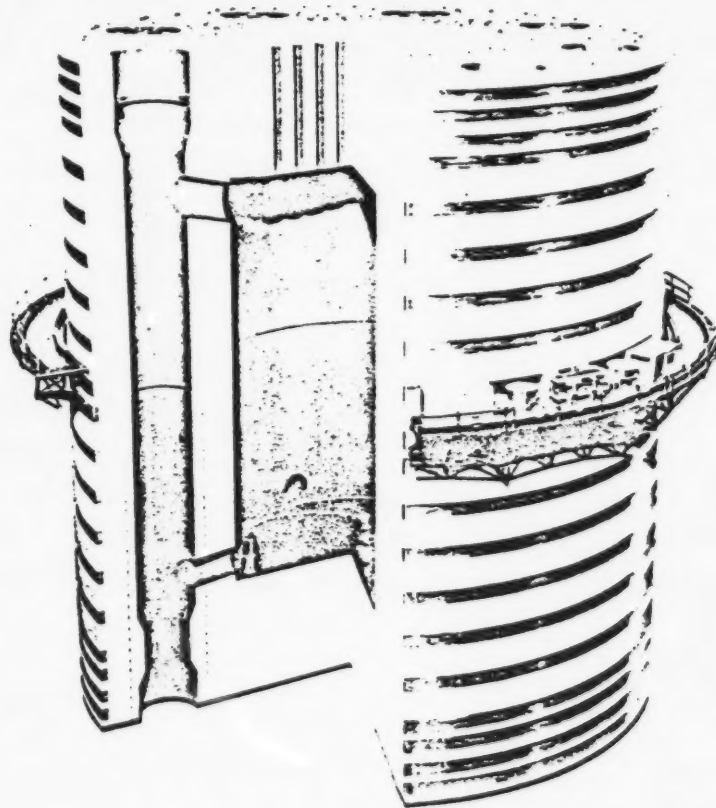
Two of the latest nuclear power stations let by the CEGB in their AGR programme are stations at Hartlepool and Heysham. The station at Heysham is being built on the basis of replication of the Hartlepool station, and each station has two cylindrical pressure vessels housing the reactors, with each reactor producing 660 MW of power.

The vessels are 13m internal diameter and 18.28m internal height with barrel walls 6.4m thick and end caps 5.48m thick. The barrel walls contain eight equally spaced vertical holes 2.74m diameter running full vessel height which contain boiler pods. Housing the boilers in the vessel walls in this way means that the boilers can be removed for servicing or renewal. There is an added advantage that much of the internal shielding can be eliminated and a much more compact reactor vessel results.

Because of the limited space available in the vessel walls for hoop prestress, a special wire winding system was developed whereby wire can be wound directly into steel channels formed in precast units which form the outside surface of the vessel. The wire is 5mm diameter and since it is tensioned before being laid on the structure, no duct friction losses are incurred. Reduced anchorage forces obviate the need for large ribs on the outside surface of the vessel which remains clearly cylindrical. Vertical prestress is by CCL 28/17.78mm tendons.

Special computer programmes have been developed which can cope with the three-dimensional analysis of a heavily penetrated structure. These are based on dynamic relaxation and finite elements methods.

The Hartlepool and Heysham vessels have been developed to their present state against a continuous background of structural and materials research. This included model tests of whole vessels and tests of model end caps only together with full programmes of investigation into concrete properties providing data used in the design.



A model of the 'podded boiler' style pressure vessel with the wire winding prestressing machine as developed for Hartlepool nuclear power station.

In its application to the European Economic Community for demonstration of Prestressed Concrete Pressure Vessel Technology for Coal Liquefaction Projects, Taylor Woodrow Construction Limited used the following approach:

Extractor Vessel Design

The extractor vessel will comprise a steel or ceramic shell, encased in prestressed concrete which will resist the stresses produced by the high operating pressure. The concrete will provide thermal insulation and if necessary, cooling pipes could be incorporated in the concrete on the outside of the extractor vessel shell. Taylor Woodrow have developed this technology for Prestressed Concrete Pressure Vessels for the Nuclear Power Industry and it has the following advantages over steel pressure vessels:

1. Vessel Dimensions

Large diameter vessels at high pressures require thick walls to withstand the high stresses. A steel pressure vessel has its wall thickness limited by the thickness of steel plates which can be welded together, however, with a Prestressed Concrete Pressure Vessel, there is no corresponding limit to the quantities of concrete and prestressing which can be used. Wall thicknesses up to 5 meters are in use.

2. Safety

Whereas the failure of a single weld could seriously endanger a steel pressure vessel, the stresses in a

Prestressed Concrete Pressure Vessel are shared by a multiplicity of individual elements. A number of these are redundant, so the failure of one element would not jeopardise the structure, and this provides intrinsic safety.

3. Construction and Maintenance

The construction and inspection techniques for large Prestressed Concrete Pressure Vessels have been shown to be much simpler than for large thick walled site welded steel pressure vessels. This should lead to lower construction and maintenance costs for commercial plants.

4. Configuration

A number of high pressure vessels and inter-connecting piping can be encased in a single prestressed concrete shell. This increases design flexibility as well as providing economies of scale.

Another concept by T.Y. Lin International and Ralph M. Parsons Company is based on integrated, multiple-cavity, prestressed concrete pressure vessels, for large plants for converting coal into gas and oil (gasification and liquefaction). It centres on the provision of a number of cavities within one large prestressed concrete container, such that the internal pressure exerted by the various cavities will neutralise one another, economising the entire containment.

A DOE study was based on the concept of a cylinder with an outside diameter of 10 to 20m and height 30 to 75m (Lin, 1978). To resist bursting pressures, the

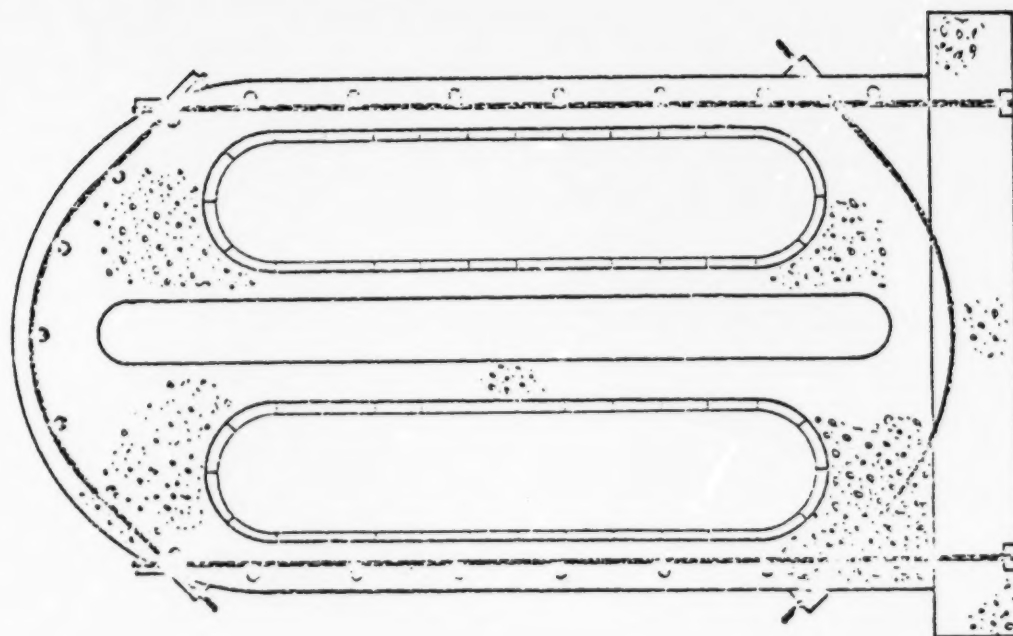
cylinder is compressed by circumferential and vertical tendons (Figure 12-3). The internal cavities are made gas and liquid-tight by a thin steel liner, which also serves as formwork for the cavities during construction. For vessels subjected to high temperatures, it is necessary to include a suitable cooling system, similar to that already developed for coal conversion vessels, to control the temperature at the interior surface of the vessel to within design limits.

Typical details are as follows:

- concrete walls 3 to 9m thick;
- prestressing tendons stressed to 500t each;
- steel liners for the cavities, approx. 12mm thick;
- refractory inside the steel lining;
- cooling system outside the steel lining;
- sealing coat on the outside face of the vessel.

In general, the advantages claimed by Lin and Parsons are:

- low direct cost;
- low maintenance cost;
- easily available materials;
- fast construction;
- large vessel size;
- elimination of high-pressure pipework and accessories between small vessels;
- moldability, to meet any vessel shape and form irregularities;
- safe failure characteristics;
- reliability;
- better impact and fatigue performances.



PRESTRESSED TENDONS

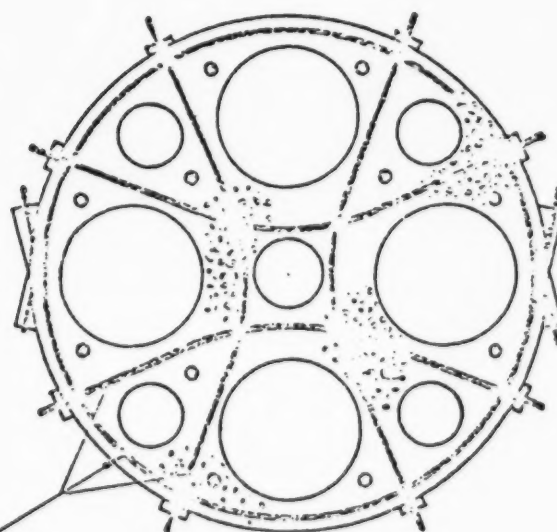


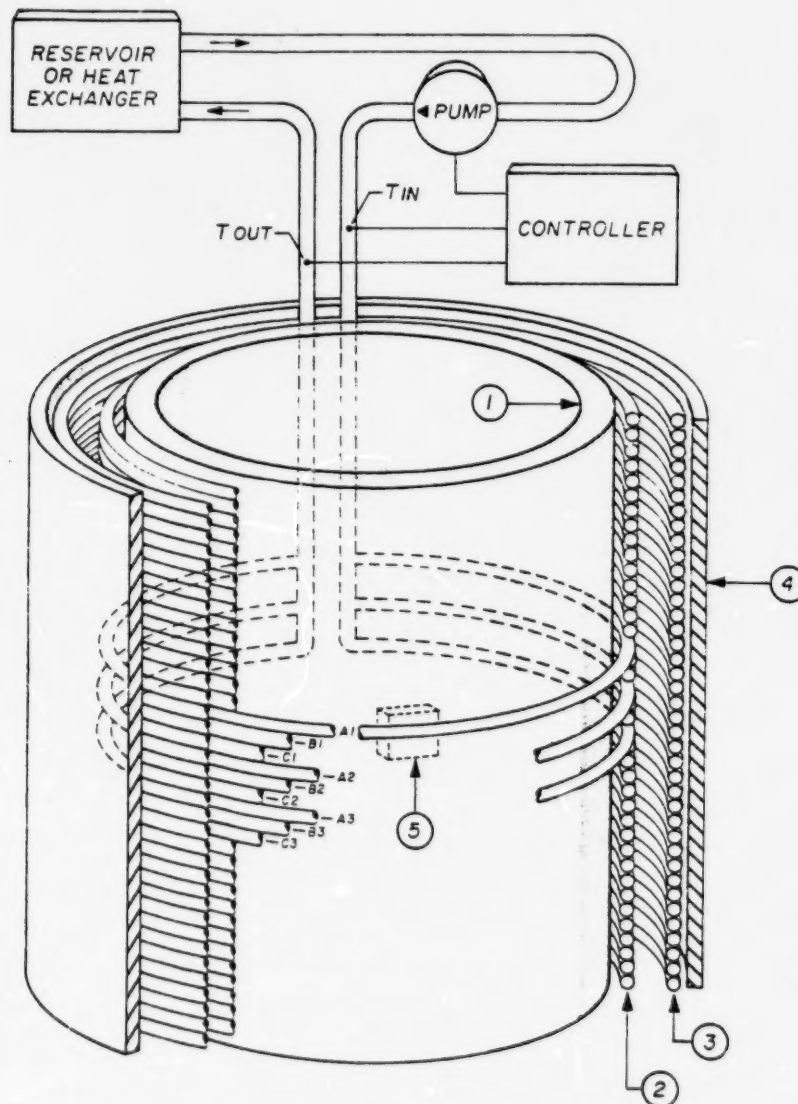
FIGURE 12-3 - Coal Conversion
Prestressed Concrete Multi-cell Pressure Vessel.

Although Lin claims that large cost savings of concrete versus steel can be achieved, judgement on this claim is reserved for the evaluation being outside the scope of this survey/forecast.

12.1.4 "MEGACOOON" PRESSURE VESSEL CONCEPT

The "Megacoon" is a conceptual compound reactor designed as a substitute or extension of the conventional steel vessel technology - Figure 12-4. It consists of essentially two separate components which serve three functions: a lightweight fiber-wound outer cocoon which holds the pressure and a computer controlled active thermal shield which safeguards the cocoon from excess heat exposure as well as monitoring and localizing any development of hot spots from the possible degradation of the inner refractory wall (Loo, 1981).

- | | |
|--------------------------------|-----------------------------|
| ① REFRACTORY BARRIER | ④ COMPOSITE PRESSURE VESSEL |
| ② PRIMARY ACTIVE HEAT SHIELD | ⑤ POTENTIAL HOT SPOT |
| ③ SECONDARY ACTIVE HEAT SHIELD | |



KBL 816-10052

Figure 12-4

A schematic illustration of a composite pressure vessel with computer controlled active heat shields.

(Source: Billy W. Loo, 1981).

12.1.5 FUTURE CANADIAN STEELMAKING CAPABILITY

For the future markets, while interest is expressed, no plans have been made by either company to actively respond to the emerging market, largely because of the belief that the market will be too small for an equitable investment. Of course, given sufficient market size and the possibility of integrating and gradually phasing in production without building of an entirely new or dedicated facility, one of the steelmakers indicated a positive interest. The same company is currently beginning to evaluate the production of clad steel for various applications.

The expansion of the Canadian mill capability to 300 mm (12 inch) plate thickness of currently produced steels would require an investment (1981 dollars) of about \$60 million to \$90 million. To establish an entirely new mill for the currently common alloy pressure vessel steels would cost over \$300 million. This level of investment would likely be attractive only if the market share were 250,000 t/y and over. It must be noted, however, that the forecasted market demand is insufficient to trigger the needed level of investment for new plants to produce the type and quality of steels needed. Therefore, we see little Canadian contribution to future steel-based material improvements or new developments other than in universities and by CANMET. Project owners and fabricators will continue to rely on imports. In the U.S., Europe and particularly Japan, material developments are actively being pursued.

12.2 FABRICATION

12.2.1 CURRENT FABRICATION CAPABILITY

At least six or seven fabricators across Canada have the current capability of constructing pressure vessels of up to 100 mm (4") wall thickness with three fabricators actually having produced 150 mm (6") thick vessels of up to 400 tonnes in weight for nuclear or petrochemical service.

Most fabricators differ in market coverage as they differ in areas of particular strengths. While those fabricators with nuclear industry experience have more expertise in the using and welding of alloys, on average, the capability of stainless steel fabrication is well distributed.

In carbon steel, only one vessel with a wall thickness of 216 mm (8.5") in layers (others up to 150 mm (6")) has been fabricated in Canada. On occasions, prefabricated thick wall cylindrical parts (cans) were imported and welded into complete vessels in Canadian shops.

In detail, Canadian fabricators can currently:

- work under ASME approval including Section VIII, Divisions 1 and 2 (in addition to other approval bodies);
- jointly dispose of several thousand tonnes of product per month;
- handle single pieces of equipment of up to 400 tonnes of weight;

- roll carbon steel plate hot of up to 203 mm (8") thick, and cold of up to 127 mm (5")
- weld with automated and semi-automated welding systems for circumferential and longitudinal welds and welding of nozzles to the vessel;
- use the following welding systems - electroslog, submerged arc (single and twin), TIG and MIG:
- weld up to 216 mm (8½") thick material;
- heat treat all the requirements as per Code and (large) size equipment requirements;
- quality control their products to meet all of the Code requirements.

Several of the fabricators have well developed marketing skills in the product areas of their respective strength in which they are generally highly competitive to the extent that about half of the larger firms successfully serve export markets.

Canadian fabricators have produced such diverse equipment as:

- reactors, converters, distillation columns, scrubbers, contactors, heat exchangers, boilers, furnaces, kilns; for subsea applications - wellheads, service chambers, submersibles, diving chambers, others.

There is fabrication expertise with all types of steels, e.g., carbon, light alloys, stainless, nickel, monels and others.

The very high pressure equipment built includes heat exchangers, 68,900 kPa (10,000 psig) and synthesis columns/converters in single or multi wall construction.

12.2.2 FUTURE PRESSURE VESSEL DESIGNS

12.2.2.1 GENERAL

From the conversion process design point, the reactor required is of tubular geometry suiting the required space velocity and contact time, if a catalytic process is involved, or residence time under pressure, temperature and hydrogen conditions as needed for the degree of conversion severity desired. The internals of these vessels and their nozzle connections to the other process equipment are primarily process dependent and no major changes will occur in the foreseeable future.

Process evaluation and process technology forecasting lead to the conclusion that no process related changes aside from some improvements will be made.

Steel as stress bearing member of pressure containers will continue to be the long term base material. For severe service, the design options will include:

- i) mildly or heavily alloyed steels;
- ii) layered combinations of stress bearing materials and materials that resist the physical/chemical attack - likely from prefabricated clad plate;
- iii) forged cylindrical sections (cans) eliminating longitudinal welds, thick plate manufacturing, thick plate rolling.

Pressure vessel designs are dependent on the materials used for construction. Steel as the current heavy pressure vessel construction material, may experience some competition from concrete in the future. While this will be likely a decade away, emerging concrete fabricating techniques would greatly change the vessel designs. Concrete is a competing material to steel - it is discussed in subsection 12.1.3.

Following is a design analysis for wall construction of vessels made from steel.

12.2.2.2 REACTOR DESIGN CRITERIA AND SELECTION

Evaluation Criteria

The primary criterion for evaluation of alternate designs of the reaction containment system for high pressure, high temperature and hydrogen rich service is safety.

Failure of such a pressure vessel can take place as a result of over pressure, over heating or both. Corrosion modifies the level at which the critical temperature and pressure occur.

The additional criteria are predictability of response to temperature and the pressure (controlled by external sources to the reactor vessel). External insulation for heat loss retention and personnel protection is not included in this discussion.

Solid Hot Wall

Assuming the shell is made of 2½ Cr-1 Mo low (S,P,Sn, Si,Mn) alloy residual steel, stainless weld overlayed, the design of the pressure vessel is by well established procedures but requires analysis per ASME Section VIII, Division 2.

Fabrication of such vessels requires special shop expertise, but can be shop completed - the only handling problems being size and weight and transportation restrictions.

The maintenance of these vessels is relatively minor consisting of inspection with occasional overlay repair. The design, fabrication and maintenance of the internals and sub-components is relatively simple.

The solid hot wall vessel has a rather high heating mass and does not respond rapidly to fluctuations in the heat of reaction. Although this may provide a stabilizing effect, it requires immediate corrective action should a significant temperature excursion occur.

The good conductivity of the shell in contact with the process makes temperature distribution measurement simple and provides a means for monitoring operating conditions at multiple locations.

Because the shell, nozzles and internals are at essentially the same temperature, the potential for thermal fatigue is low.

Internal Insulation (Refractory) and Hot Wall

This system assumes the potential for process fluid penetration of the insulation. It has a 2½ Cr-1Mo shell with stainless weld overlay designed for high temperature hydrogen exposure but with internal insulation to reduce normal exposure temperature.

The design of the shell of this system is by well established design techniques to Section VIII Division 2. The insulation system must be carefully selected and designed to be effective.

Hot wall insulated systems, although the most expensive, would appear to offer a comfortable margin to survive a severe local or general temperature excursion. However, this is totally dependent upon the integrity of the internal insulation. In this regard, the following factors must be considered.

Because of the larger shell diameter to accommodate the insulation (typically up to 100 or 150 mm thick), the shell will be heavier than a "solid hot wall" uninsulated vessel of the same capacity. The Application of insulation is a special skill generally supplied by subcontract. It may have to be done in the field, requiring high integrity and careful detailing at penetrations and points of attachment for internals.

The maintenance of the shell of this vessel is largely inspection surveillance. Overlay inspection and repair is complicated by the presence of the internal

insulation. The insulation, however, must be well maintained, requiring repair of minor deterioration points to prevent in-service failures. It is the fear of insulation failure which prompts the consideration of hot wall reactors designed with or without internal insulation.

The design, fabrication and maintenance of internal support points and penetrations are critical items with internally insulated systems, since these are the points where insulation failure is most likely to occur. The normal operating conditions will produce a large thermal gradient between the internals and the shell, so the attachment points require very special consideration. The requirement for fatigue analysis under ASME Section VIII, Division 2, depends upon the design approach taken:

- i) If the attachment is made directly to the pressure boundary, fatigue analysis may be required.
- ii) If attachment is made through a flexible member which absorbs the thermal gradients and cycling, at a location remote from the point of attachment to the pressure boundary, then fatigue analysis will probably not be required.

The internal insulation system provides an effective isolation of the shell to any operating thermal transients, but because of the low heat mass and low thermal conductivity of the insulation, it cannot provide any stability during process swings.

While hot spots due to insulation failure or fluid bypassing are not as critical as for "cold wall"

design, such hot spots must be detectable and will require immediate operator attention. The detection of such hot spots presents some problems because of the large surface area involved.

Measuring temperature distribution within the reactor bed is complicated since temperature detectors must penetrate the insulation.

Laminated Hot Wall

This is a multiple layer vessel made with:

- i) Innermost shell course of $2\frac{1}{2}$ Cr-1 Mo with stainless weld overlay.
- ii) Remaining shell course of $2\frac{1}{2}$ Cr-1 Mo or carbon steel.
- iii) Solid $2\frac{1}{2}$ Cr-1 Mo forged heads and nozzles weld overlaid with stainless steel.

Laminated wall construction may offer the best cost potential. Service experience is limited.

There is some question as to how the designers would analyze the interaction of the layers for the various operating cycles involved.

Although laminated construction requires new know-how, the material and fabrication requirements are not as stringent as for solid wall because of the smaller thickness of each layer.

Design, fabrication and maintenance of internals is essentially the same as solid wall design, requiring attention to corrosion only.

The response of these systems to transient temperature conditions is not well known. A significant thermal excursion would require immediate shut-down, followed by extensive inspection.

The measuring of temperature distribution in the system is relatively simple on the innermost course, but difficult to do meaningfully as far as the through-shell temperature is concerned because of the layer insulation effect.

As the technology advances, laminated hot wall construction holds good promise for the future.

Internal Insulation - Cold Wall

This system has a shell designed to run at a low temperature which is protected by internal insulation.

The design of the shell in this system is relatively conventional, since it requires only carbon steel. However, because of size and thickness a Division 2 design with the necessary analysis is still indicated. The internal insulation becomes very critical since the entire viability of this design hinges on its continued effectiveness.

The attraction of this design is that it represents the minimum cost of the designs considered and fabrication of the heavy wall carbon steel shell provides a greater choice of vendors world wide. However, installation of the in-

ternal insulation to the required integrity is critical and most probably must be done in the field.

Maintenance of the shell is the simplest of all alternates. The internal insulation must be maintained in near perfect condition at all times since a failure in service would require instant shut-down.

The design, fabrication and maintenance of internals is a critical item with a cold wall insulated reactor since it is at penetration points of this insulation that failure and bypassing is most likely to occur. Bypassing results in hot spots on the shell with potentially disastrous results.

The insulation system provides an effective isolation of the shell to any operating transients, but the low heat mass and thermal conductivity cannot supply any stabilizing effect on process swings. A significant temperature excursion will not affect the pressure shell.

Measuring temperature distribution in the system is complicated by the internal insulation for temperature detectors must penetrate the insulation. The temperature of the shell can only be monitored over the entire area of the shell by temperature sensitive paints. Surveillance becomes a difficult task on reactors of this size.

Conclusions

Hot wall design is feasible and safe for vessels of up to 4.5 m inside diameter, designed for pressures of up to 20,000 kPa and 450°C and with an H₂ partial pressure of

about 15,000 kPa. The applicable code is ASME Section VIII, Division 2, using 2½ Cr-1 Mo, normalized and tempered material. Design requirements for the system, as well as the reactor itself, are well understood.

A hot wall design is safe, and with a reliable instrumentation system that is redundant and well maintained, the operation of the process system can be well monitored and controlled.

It is felt that all of the instrumentation necessary to detect the above conditions has been proven both in design and application. Availability and demonstration of good high-reliability temperature measuring systems, and practice of operating discipline to avoid operation beyond the defined temperature limits, have been well proven.

Where the weight of the reactor or the shipping diameter is a limiting factor, hot wall design has a size advantage for comparable process capacity, requiring fewer reactors to reach design capacity in large plants.

12.2.3 FUTURE TESTING REQUIREMENTS

While hydrostatic testing of pressure vessels will continue to be the most effective testing method, it will be desirable to have a method available which will during hydrostatic testing, signal a potential failure (before it actually occurs).

Accoustic emission is one such technique, but instrumentation and data interpretation require further development to become a reliable commercial method for shop and field applications.

12.2.4 FUTURE FABRICATION TECHNIQUES

It is very likely that the future fabrication techniques used by Canadian fabricators differ from those applied by international fabricators.

In Europe, the U.S. and Japan where very thick plate light alloy steels were produced, formed and welded in the past, the trend is to continue with this practice, but refine materials and fabrication techniques including multi-layered vessels. Countries with an active nuclear power plant industry will further the entire fabrication spectrum of their thick section capability, even possibly based on concrete (as in the U.K. and Germany). Japanese fabricators will further increase the market of very large and complex forgings with benefits accruing to the buyers of heavy pressure vessels.

In Canada, none of these developments is foreseen if free market conditions continue to prevail. Canadian fabricators though should find opportunities in importing prefabricated parts of cans for assembly into pressure vessels in a shop directly located at the project site, thereby eliminating most of the transportation restrictions. Alternatively, fabricators may find a market niche in building multi-layered vessels using their current equipment and skills for thin and medium thick plate construction.

For the future requirements of fabricating very heavy wall pressure vessels, judging by a balanced shop capability and an active marketing approach, only a few fabricators are currently seen to be actively interested and gearing up their operation to cover the very heavy end of the pressure vessel market in addition to their current spectrum of fabricated products.

While plate forming, pressing or rolling is more a function of appropriate investment into large equipment rather than a matter of technology and the availability of skilled personnel, it could be seen that the economic advantage would exist if a specialization by one or two firms would be developed. These firms would then supply the various fabricators with preformed parts at a potentially quite economic price. These parts could be either segments of the vessel shell from single plate or clad plate, or could be fully prefabricated cans, either welded or forged. The fabricators would then weld the parts into the respective pressure vessels with heavy emphasis on a specialization and setting up these parts, welding and integrating of nozzles. It is assumed here that the welding of six or ten or twelve inch plate or even clad plate will require a specialization in welding procedures as well as welding process systems.

Regarding quality control of the fabrication of material and vessel, it follows from the investigations of this study that quality control will have to play a major role for these very heavy vessels. Independent

of source of steel and location of fabricator, considerably more stringent procedures than are currently required under the ASME Section VIII, Div. 1 or 2, will have to be followed to assure safe operation of the vessels as well as cost effective production. This situation may suggest that an owners representative will follow each manufacturing and fabrication step up to and including the vessel installation and testing within the process system to assure continuity in the quality control procedure.

Since it is highly likely that the materials for heavy pressure vessels for Canadian projects will have to be imported, while domestic fabricators will have the facilities, expertise and skill to produce the vessels, it is likely that for the fabrication of the very heavy vessels, the following concept will be used:

- import of alloyed or clad steels;
- prefabrication of shell segments or cylindrical parts by specialist job shops;
- cost efficient transportation of the prefabricated parts to a preliminarily set up assembly shop very close to the project job site;
- assembly of pressure vessels with highly automated welding systems at a location very close to the job site;
- transportation over only a few miles with no transportation restrictions and erection in one piece at the job site.

The vessels would be virtually shop fabricated, eliminating the need for a final circumferential weld during erection at the job site with subsequent needs

for heat treatment and radiographic inspection under field conditions.

12.2.5 FUTURE CANADIAN FABRICATION CAPABILITY

A few of the Canadian fabricators are well equipped to meet the increasing demand for heavy wall pressure vessels. A large share of this emerging market will be in the medium thickness range of 100 to 203 mm.

To successfully fabricate vessels in this thickness range and of light alloy material requires the provision of only a few single elements:

- increased rolling/forming capability (which could cost approximately \$10 million per shop);
- welding procedures for the thick plate alloy materials;
- commercialization of narrow gap welding technique;
- fabrication procedures for layered vessels.

Additional, rather marginal, equipment procedures or skills will be required which could be considered part of good business practice.

There are about four manufacturers who could, within the very short timeframe, build vessels in this wall

thickness range. In Canada, they will likely be competitive with foreign suppliers.

Considering, however, the very thick wall range of 250 mm (10") and up, then the opportunities for Canadian firms are sharply reduced. Heavy investment would be required to establish the capability against a rather small market and an overwhelming amount of foreign firms who have already proven their capability. These foreign firms often receive substantial financing assistance from their governments for export work. Table 12-1 lists some of the foreign competitors.

Canadian fabricators can likely become competitive only - not considering exchange rate developments - if they develop a specialization in layered vessel construction and/or receive financing assistance from the Canadian government(s).

None of the manufacturers will, in the foreseeable future, have a large forging capability. They may, therefore, face the need to import the forged cans for welding into vessels here. Alternatively, they could import prefabricated cans from single plate or clad plate material.

TABLE 12-1 - INTERNATIONAL FABRICATORS
OF HEAVY PRESSURE VESSELS

1. U.S.A.

- BELMAS JOVAL
- CHICAGO BRIDGE & IRON
- DELTA SOUTHERN COMPANY
- GENERAL WELDING WORKS
- NOOTER CORPORATION
- RILEY-BEAIRD, INC.
- STRUTHERS WELLS CORPORATION
- WYATT'S INDUSTRIES

2. JAPAN

- HITACHI LIMITED
- HITACHI SHIPBUILDING & ENGINEERING COMPANY LTD.
- ISHIKAWAJIMA MAZIMA HEAVY INDUSTRIES
- JAPAN STEEL WORKS
- KOBE STEEL LIMITED
- MITSUBISHI HEAVY INDUSTRIES
- MITSUI SHIPBUILDING & ENGINEERING COMPANY LTD.
- NIPPON KOKAN KK
- SUMITOMO HEAVY INDUSTRIES, LTD.

3. FEDERAL REPUBLIC OF GERMANY

- BORSIG AG
- DEUTSCHE BABCOCK & WILCOX
- GUTEHOFFNUNGSHUTTE (GHH)
- KOERVER & LERSCH
- KRUPP
- LEFFER, H. & CO.
- TEYSSSEN MACHINENBAU AG

4. ITALY

- NUOVO PIGNONE
- BREDA TERMOMECCANICA
- BOSCO INDUSTRIE MECCANICHE S.p.A.
- A.T.B.

5. FRANCE

- C.M.P.

12.3 ANTICIPATED COST OF HEAVY WALL PRESSURE VESSELS

An estimate of the cost of future very heavy wall pressure vessels is made here for the purpose of information and not for input into the demand forecast. There is no reason to believe that the actual future cost of these vessels will have any impact on corporate decision making on upgrading/conversion projects.

A "typical vessel for a feedstock throughput equivalent to a final plant output of about 1592 m³/d (10,000 b/d) has dimensions of 3.5 m inside diameter and 40 m height and is designed to operate under the following conditions - 15,000 kPa and 430°C. It is a hot wall design as most process developers currently envision.

When fabricated from ASME SA-387, Grade 22, Class 2 and designed in accordance with ASME VIII Division 2, its wall thickness is about 300 mm. It has several internal pipes running over most of the height and additional plates, baffles, pipes and fittings. Most of these internals are welded to the shell and are made from SA-387, Grade 22, Class 2 material also.

The shell inside is furnished with two weld overlay passes of 309 SS (1st pass) and 347 SS (2nd pass) each 3 mm (1/8") thick.

This vessel has about 25 nozzles ranging from 25mm to 1.0 mm in diameter, of which about three to five are refractory lined to withstand high velocities of solids/liquids or solids.

Furnished with a spherical top and a 6 m long skirt, the weight of this vessel is about 1000 tonnes.

Its price FOB, Canadian fabricator in 1982-\$, would likely be \$17 million, (\$5 million for materials) including:

- steel price FOB U.S.;
- exchange rate;
- custom duty;
- cutting wastage;
- consummables;
- direct and indirect labour;
- plant amortization;
- overhead and profit;
- federal sales tax.

The requirements for a typical train of 1600 m³/d (10,000 b/d) capacity coal liquefaction plant includes 23 heavy wall pressure vessels costing about \$66 million (1982) for a total tonnage of about 5290 tonnes. More details are presented in Table 12-2.

For comparison, the heavy wall pressure vessels installed in the Syncrude oil sands plant in 1978 have the following wall thicknesses and dimensions:

the naphtha hydrotreaters for a capacity of 3987 m³/d each - were fabricated in France -

TABLE 12-2
OVERVIEW OF TYPICAL EQUIPMENT REQUIREMENTS AND COST
FOR A PLANNED U.S. COAL LIQUEFACTION PROJECT
(Train Capacity 1600 m³/d)

VESSEL	DESCRIPTION	QUANTITY	APPROX. DIMENSIONS AND WEIGHT			APPROX. UNIT COST* \$CAN-MILL. (1982)
			Wall Thickness (mm)	I.D. (m)	Height Weight (m) (Tonnes)	
LIQUEFACTION REACTOR	2½ Cr-1 Mo, 2 SS weld overlays	2	320	3.5	40 1300	17.0
EFFLUENT SEPARATOR	2½ Cr-1 Mo, 2 SS weld overlays	2	200	2.5	15 250	3.3
HIGH PRESSURE LETDOWN DRUM		2	240	3.1	7 235	3.2
QUENCH TOWER	A-516, 3mm SS clad	2	100	2.0	8 80	1.4
WASH TOWER		2	100	1.5	15 60	0.5
HIGH PRESSURE SEPARATOR	1½ Cr-½ Mo, 2 SS weld overlays	2	150	2.0	5 80	1.3
DECANTER	A-516	4	125	2.5	14 200	1.0
If bottoms processing is applied, a resid-gasification system may be used:						
GASIFIER	1½ Cr-½ Mo, re- fractory lined	3	80	3.0	13 120	2.5
SLAG LOCK HOPPERS	1½ Cr-½ Mo.	3	65	1.8	3 12	0.08
GAS SCRUBBER	1½ Cr-½ Mo.	1	80	3.0	10 85	1.0

* Weight and cost include completed vessels c/w internals, nozzles and skirt.

APPROX. TOTAL TONNAGE:- 5291 TONNES
APPROX. TOTAL COST:- \$66.1 MILL

two - 3.0 m I.D., 15.5 m high, 63 mm wall thickness
and 95 tonnes weight;

two - 3.5 m I.D., 11.4 m high, 63 mm wall thickness
and 89 tonnes weight;

two - 3.5 m I.D., 77 m high, 63 mm wall thickness
and 61 tonnes weight;

the gas oil hydrotreaters are designed for a capacity of 7197 m³/d each - and fabricated in Italy -

two 3.5 m I.D., 7.6 m high, 130 mm wall thickness
and 63 tonnes weight;

two 3.5 m I.D., 33.2 m high, 130 mm wall thickness
and 375 tonnes weight;

the amine contactors were fabricated in Canada -

two 2.7 m I.D., 42.3 m high, 98 mm wall thickness
and 286 tonnes weight.

12.4 FUTURE CRITICAL ISSUES

On occasion, Canadian fabricators are competitive with European or U.S. fabricators. However, they always lose out to the Japanese. In future, this phenomenon will only strengthen.

Many of the larger vessels built today have lead times of one to two years including procurement of steel plates, while their costs can reach up to \$3 to \$5 million dollars. This puts great pressure on the financial capability of a fabricator who may have an annual turnover of \$50 million.

Several of the Canadian fabricators export a large amount of their product. Restrictions of trade, i.e., import barriers, are considered undesirable, for they would provoke reciprocal actions and hurt the Canadian exporters.

It would be desirable, therefore, for the Canadian Government to provide to the domestic fabricators a program similar to the export financing assistance program and make available low cost loans for the period of vessel procurement/construction.

13. BENEFITS TO CANADA

Two levels of benefits can be identified - a) the direct benefits derived from the manufacture of those vessels in Canada which will be commonly contracted to foreign manufacturers, and b) the spin-off benefits possible from government triggered research and development programs.

Canadian fabricators could capture 550 heavy wall pressure vessels of up to 250 mm wall thickness. On average, each vessel will cost at least \$2.0 million (1982). Of this unit cost, about one third will be cost of imported steel. Total sales would be \$Mill. 1,100, accounting for balance of payment contribution \$667 Million (including about 10,000 manyears of jobs).

If the Canadian fabricators become sufficiently competitive to win all of the Canadian heavy wall pressure vessels, they would be competitive in the international market and could capture a portion of the world market.

The spin-off benefits from government sponsored research and development programs would provide stimulation to Canadian industries related to:

- welding systems;
- consummables;
- jig makers;
- fabrication equipment and tools;
- testing and inspection equipment and services;
- instrumentation and services (for testing and inspection);

- transportation.

Further spin-offs into other industries can be expected.

14. TECHNOLOGICAL GAPS

What is needed for Canadian industry to produce very heavy pressure vessels is mainly suitable equipment. To provide it, however, the combination of market size and investment becomes critical.

It is felt feasible for Canadian fabricators to become competitive in the wall thickness range up to 250 mm (10"). To technologically achieve this, several areas lack substance, but not serious major gaps exist.

The pressure vessels of concern are already being competently produced outside of Canada. Short of importing the technology, most of the missing know-how can be extrapolated from current capability. It is best developed within the user organizations, possibly supported by publicly funded development programs.

The following areas then require further research and development work:

. Metallurgy:

- extent of possible degradation of 2½ Cr-1 Mo and similar steels during long term service;
- complete understanding of stress - corrosion cracking for alloy steels;
- complete understanding of high temperature sulfidation, low temperature hydrogen degradation and others;
- determination of toughness, fracture toughness and creep and stress-rupture requirements;

. Welding - (partially initiated by PMRL or progressing):

- narrow gap;
- plasma arc;
- electron beam;
- procedures for very thick sections;
- procedures for light alloys, e.g., 2½ Cr-1 Mo;
- procedures for strip cladding;
- automatic field weld system for very thick sections.

. Fabrication/Testing:

- techniques/procedures for layered construction;
- through-thickness quality monitoring;
- non-destructive testing (NDT) techniques appropriate for thicker wall and narrow gap welding.

. Code Application:

- amendment for ASME, Section VIII, Division 2 to cover all aspects including creep at very high operating temperatures.

. Insulation, Linings:

- spray-on concrete type refractory for field application;
- refractories sufficiently tough to survive transportation from shop to field;
- designs for penetrations.

. Operation:

- understanding of failure mechanism dependent on service environment through a simulated numerical failure analysis;

- process related distribution/behaviour of thermal loading;
- extent of possible thermal excursion on basis of state-of-art instrumentation/control system;
- response of materials to coal liquefaction environment as compared to heavy oil environment;
- in-service vessel integrity monitoring.

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APPENDIX A
WORLDWIDE PRESSURE
VESSEL CODES

Guide to ASME Sec. VIII, Div. 1



HYDROCARBON PEROXIDES. VI

Guide to British Code BS.5500

J. W. Strawson, Oil Companies Materials Association, London

3.5.2 Thickness—internal pressure

3.6.2.4, 3.6.2.5 Thickness—external pressure

4 Note 1 Rupture discs

3.5.4.2 Nozzle reinforcement

3.5.4.4 Adjacent openings

3.5.4.3.4 Limits of reinforcement

3.5.1 Thickness internal pressure

3.6.2.1 Thickness external pressure

3.6.3 Stiffening ring

3.7 G.3 Support lugs

G.3 Stiffener plate

5.8.9 Name plate

3.5.4.8 Screwed opening

4.3.6.2 Back-up strip

3.5.3 Apex angle

3.5.3 Transition (reducer) section

3.5.3 Thickness internal pressure

3.6.2.6 Thickness external pressure

3.8 Bolted connection

3.11 Jackets

3.5.6 Spherically dished covers

See detail "A"

Common header — J.10 Note 4

Nonpressure parts — 2.2.4, 4.3.5

Stop valve — J.9.3.2 Note 4

Discharge line — J.10 Note 4

Circumferential weld — App. E

Safety valve — App. J Note 4

Linings — 3.3.3

Drain — J.10.3 Note 4

Stop valve — J.9.3.1 Note 4

Inlet piping — J.9.2 Note 4

Nozzle reinforcement — 3.5.4

Welded opening — 3.5.4, 3.10, App. E

Internal structures — 3.7

Compression ring — 3.5.3.1.3

Apex angle — 3.5.3

Transition (reducer) section — 3.5.3

Thickness internal pressure — 3.5.3

Thickness external pressure — 3.6.2.6

Knuckle thickness and radius — 3.5.3.1.4.2

Attachment lugs — 2.2.4, 4.3.5

Knuckle radius — 3.5.2.2

Thickness internal pressure — 3.5.2

Thickness external pressure — 3.6.2.4, 3.6.2.5

Support skirt — 3.7, G.3.2.1

See detail "B"

See detail "C"

See detail "D"

DEFINITIONS

Design pressure — 3.2.3

Design temperature — 3.2.4

Maximum allowable pressure — Note 2

Corrosion allowance — 3.3

Joint efficiency — Note 3

Heat treatment — 4.4

Materials — Section Two

Stamping — 5.8.9

Loadings — 3.2.1

GENERAL TESTS

Hydrostatic test — 5.8.1, 5.8.2, 5.8.3, 5.8.5

Pneumatic test — 5.8.1, 5.8.2, 5.8.4, 5.8.5

Proof test — 5.8.6

Low temperature service — 3.2.4, App. D

Non-destructive testing — 5.6

Inspection — Section Five

Repairs — 4.4, 3.4, 5.7.4

Construction category — 3.4.1 & Table 3.4

NOTES

1. BS 5500:1985 Bursting discs and bursting disc assemblies.

2. Maximum allowable working pressure is equal to design pressure as calculated using actual metal thicknesses - corrosion allowance, provided.

3. BS 5500 does not use the concept of a weld joint efficiency factor.

4. Station with BS 5500 Safety valves for use in the chemical, petrochemical and allied industries in course of preparation as follows:

BS 5500:1985 Access and inspection openings for pressure vessels.

BS 5500:1985 Bolting, flanges and pressure containing devices.

Annexes, including supplements and code case interpretations are available automatically when so specified at time of purchase of part.

5. BS 5500:1985 Part 1 and BS 5500:1985 Part 2 will be withdrawn in 1989, following publication of supplementary material to BS 5500 covering aluminium and titanium alloys.

GENERAL REFERENCES

Heat exchanger tubesheets — 3.9

Tubesheets waste heat boiler type — 3.5.3

Staved surfaces — 3.5.3

Design criteria for loadings and components not explicitly covered by design formulae — Appendix A

Shells under combined loadings including wind and earthquake — Appendix B

Assessment of stresses subject to fatigue — Appendix C

Circulation of stresses from local loads — Appendix D

Thermal stresses etc. — Appendix E

Derivation of material nominal design stresses — Appendix F

Welding procedure qualification tests — 5.2

Welding and operator qualification tests — 5.2

See BS 5500:1985 Part 1

See BS 5500:1985 Part 2

See BS 5500:1985 Part 3

See BS 5500:1985 Part 4

See BS 5500:1985 Part 5

See BS 5500:1985 Part 6

See BS 5500:1985 Part 7

See BS 5500:1985 Part 8

See BS 5500:1985 Part 9

See BS 5500:1985 Part 10

See BS 5500:1985 Part 11

See BS 5500:1985 Part 12

See BS 5500:1985 Part 13

See BS 5500:1985 Part 14

See BS 5500:1985 Part 15

See BS 5500:1985 Part 16

See BS 5500:1985 Part 17

See BS 5500:1985 Part 18

See BS 5500:1985 Part 19

See BS 5500:1985 Part 20

See BS 5500:1985 Part 21

See BS 5500:1985 Part 22

See BS 5500:1985 Part 23

See BS 5500:1985 Part 24

See BS 5500:1985 Part 25

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See BS 5500:1985 Part 27

See BS 5500:1985 Part 28

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See BS 5500:1985 Part 30

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See BS 5500:1985 Part 33

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See BS 5500:1985 Part 35

See BS 5500:1985 Part 36

See BS 5500:1985 Part 37

See BS 5500:1985 Part 38

See BS 5500:1985 Part 39

See BS 5500:1985 Part 40

See BS 5500:1985 Part 41

See BS 5500:1985 Part 42

See BS 5500:1985 Part 43

See BS 5500:1985 Part 44

See BS 5500:1985 Part 45

See BS 5500:1985 Part 46

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See BS 5500:1985 Part 70

See BS 5500:1985 Part 71

See BS 5500:1985 Part 72

See BS 5500:1985 Part 73

See BS 5500:1985 Part 74

See BS 5500:1985 Part 75

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See BS 5500:1985 Part 90

See BS 5500:1985 Part 91

See BS 5500:1985 Part 92

See BS 5500:1985 Part 93

See BS 5500:1985 Part 94

See BS 5500:1985 Part 95

See BS 5500:1985 Part 96

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See BS 5500:1985 Part 98

See BS 5500:1985 Part 99

See BS 5500:1985 Part 100

DETAILS

Detail "A"

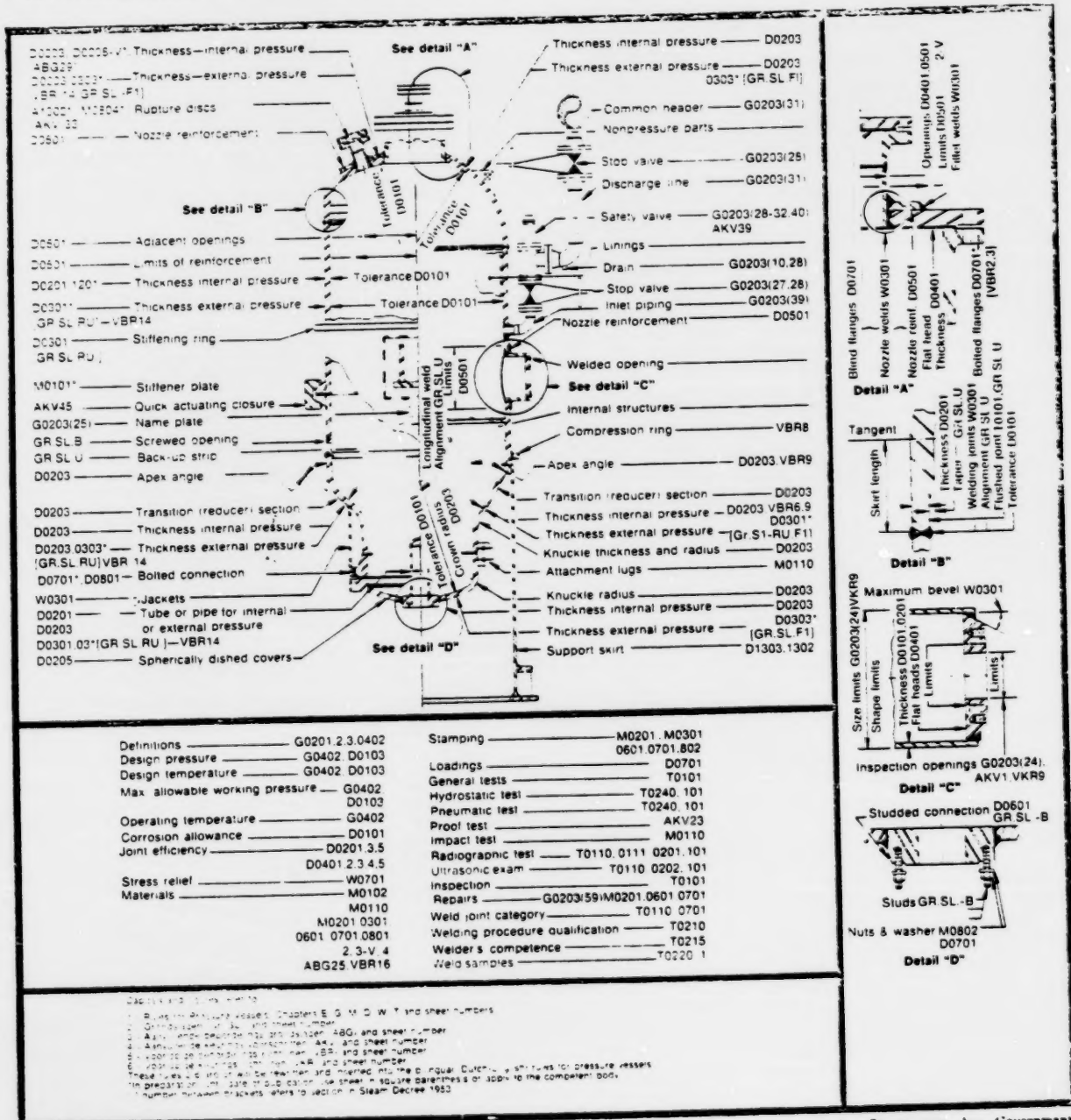
Detail "B"

Detail "C"

Detail "D"

Guide to Dutch Stoomwezen Code

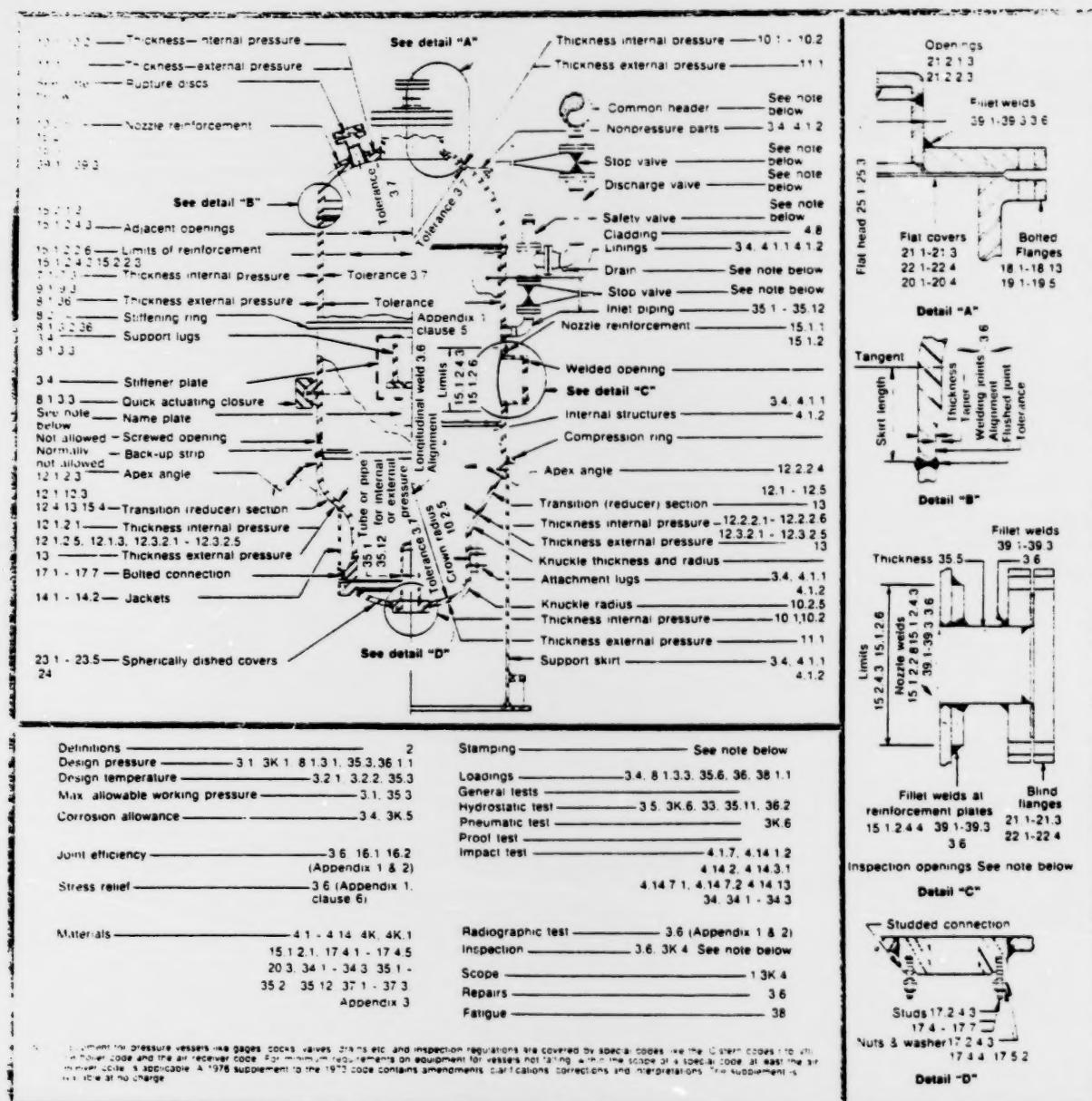
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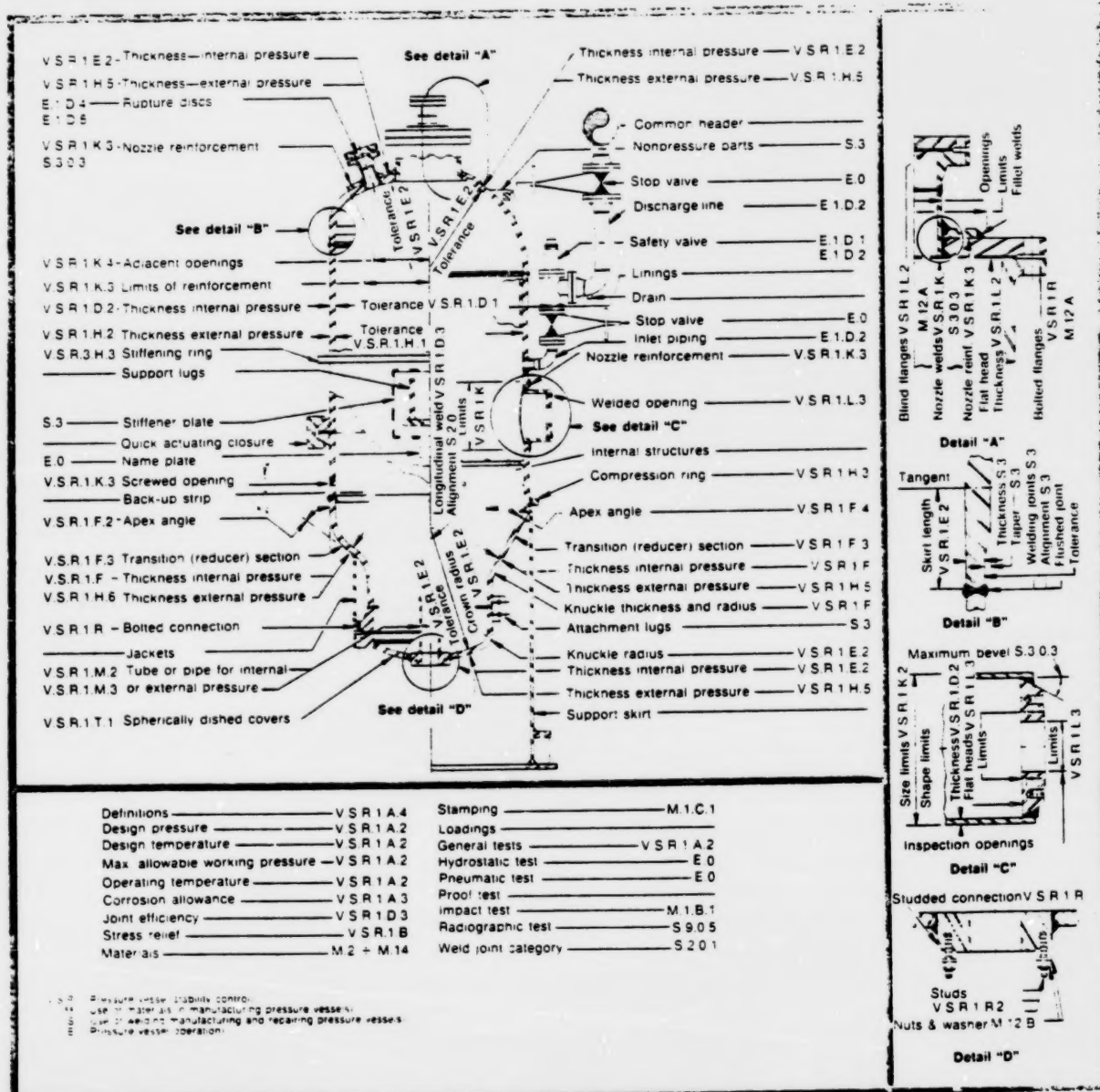


The Circle is published by Tryckkärtskommissionen IVA, P.O. Box 5073, S-102 42, Stockholm, Sweden.

A 1976 supplement to the 1973 Code contains amendments, clarifications, corrections and interpretations. The supplement is available at no charge.

Guide to Italian Pressure Vessel Code

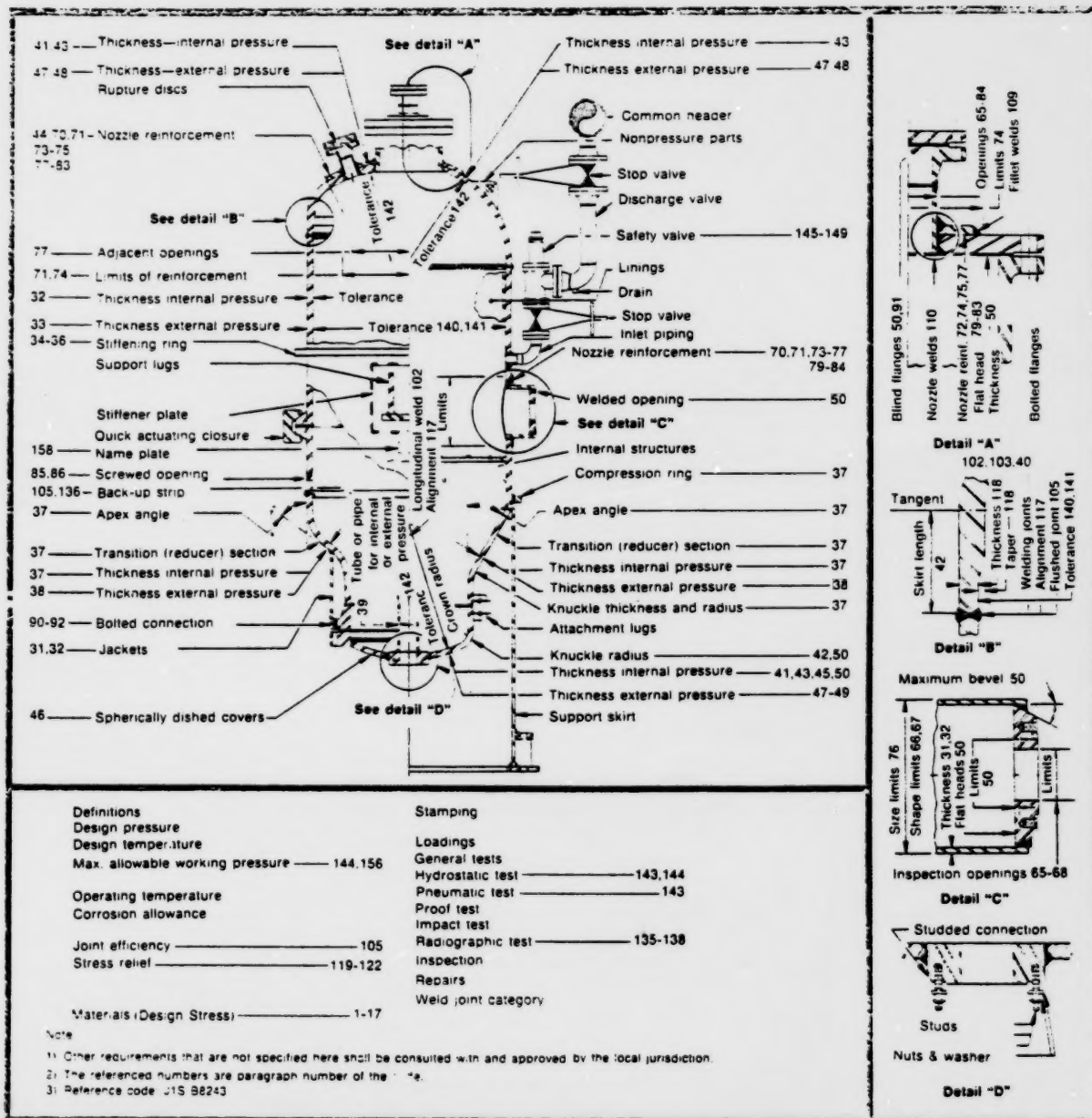
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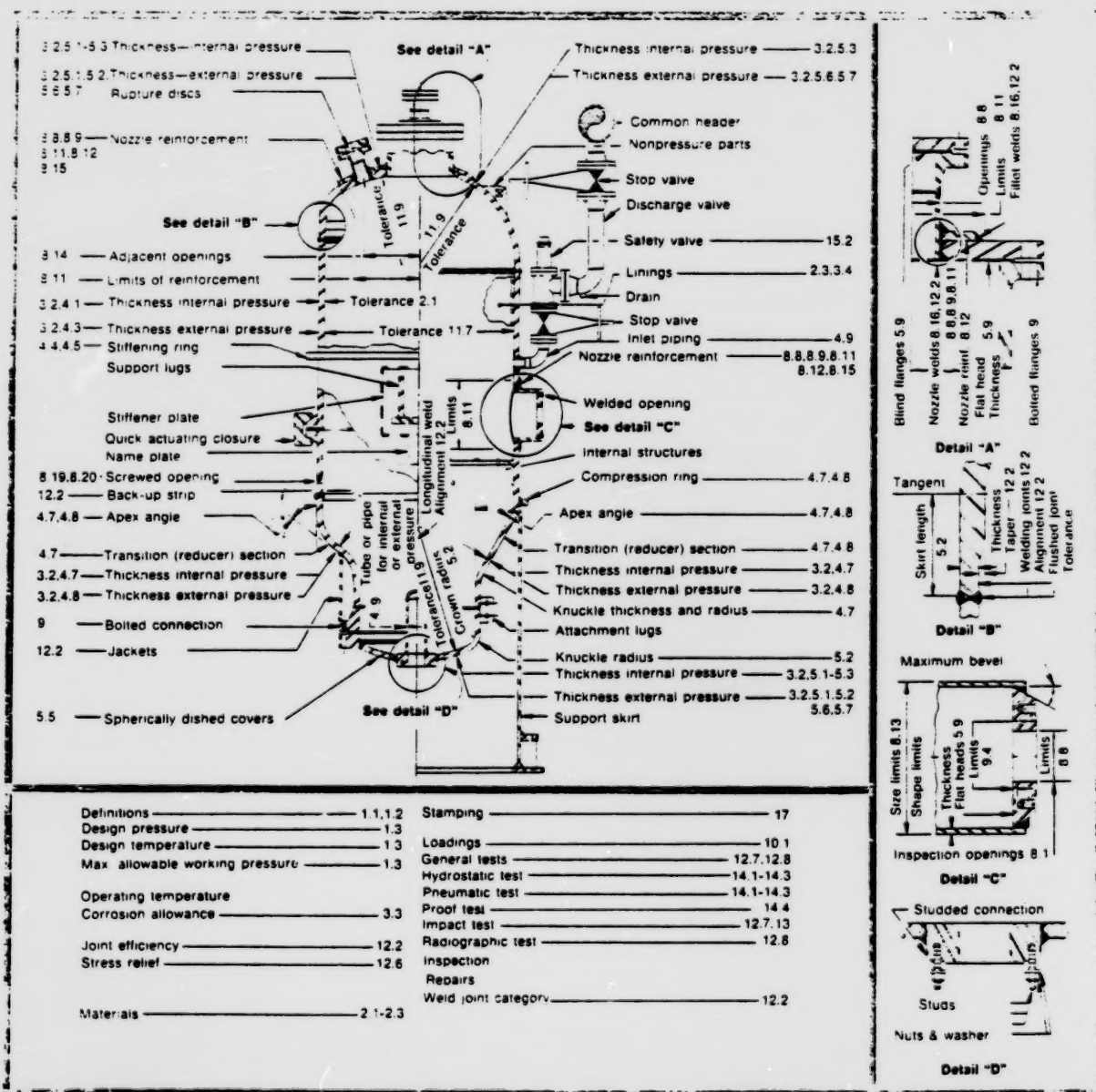
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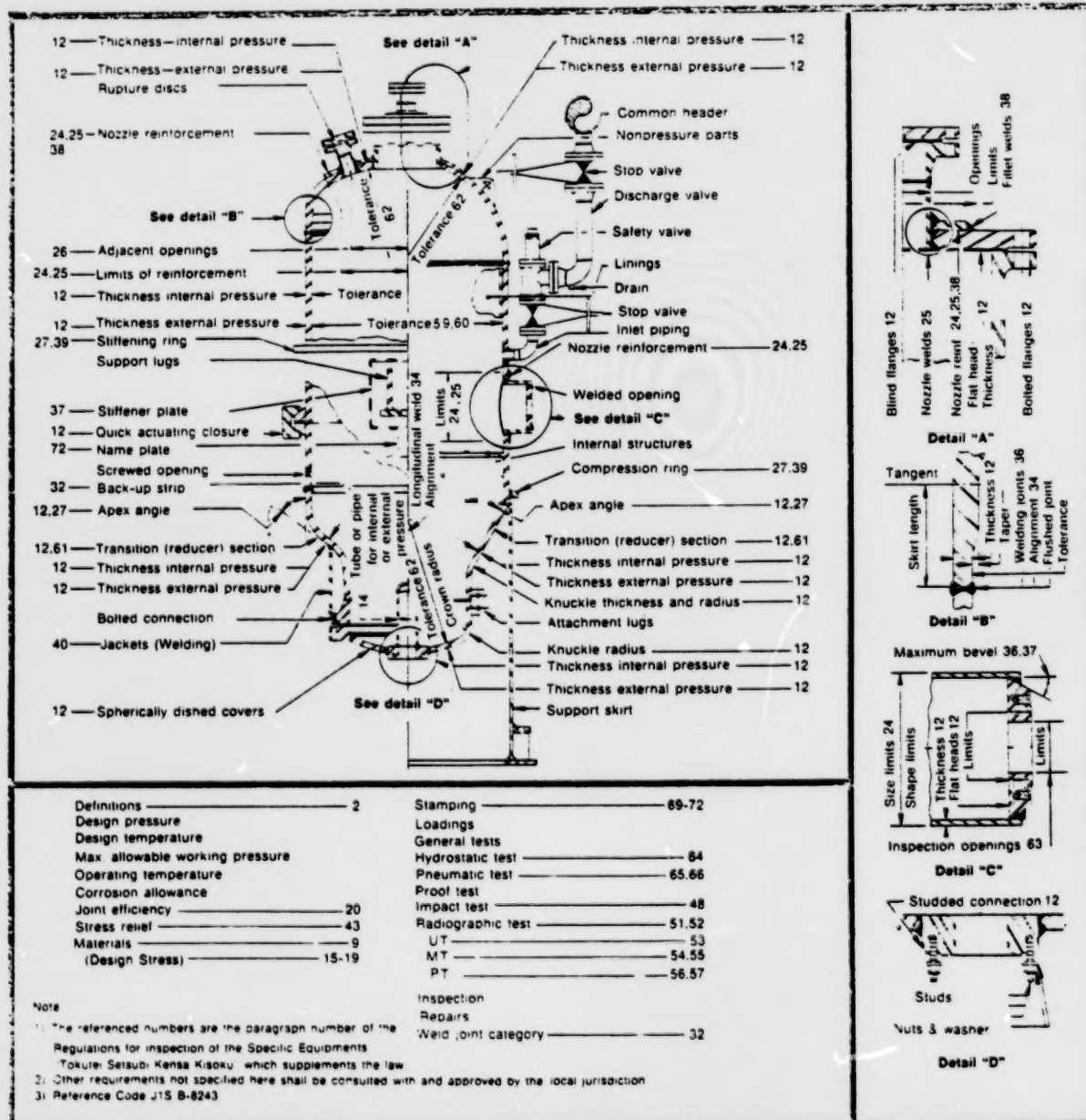
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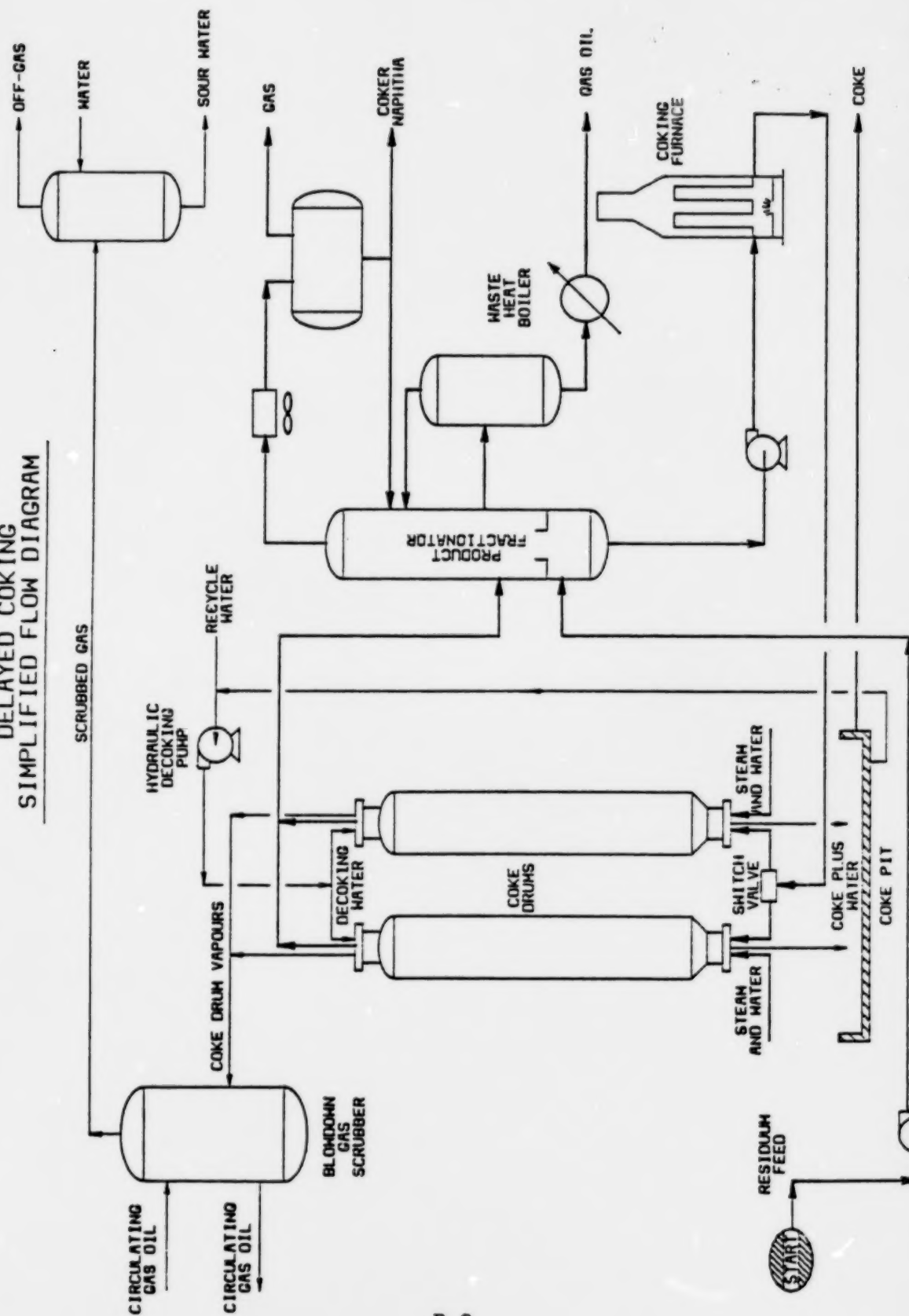
APPENDIX B
CARBON REJECTION PROCESSES

1. DELAYED COKING

Delayed coking derives its name from the process - feed bitumen is heated rapidly and then transferred to a coking drum where the coking reaction actually takes place. The process flow sheet is shown in Figure B-1. The fresh feed initially passes through fractionation and the bottom fraction is fed through the coking furnace - generally a direct - fired tubular design - to one of several large vertical coke drums. The furnace temperature and residence time are controlled to minimize coking in the furnace but to let it occur in the coke drum. The coke drums are filled sequentially, feed being switched to an empty drum when the drum in use becomes full and the coke-filled drum subsequently emptied by cutting the coke out with a high pressure hydraulic jet. Overhead product from the coking reaction comprises cracked hydrocarbon vapours which pass to product fractionation (Foster Wheeler, 1976).

Coking yields are controlled by the temperature and pressure at which the reaction takes place. Higher yields of gases (C_4 -) and coke result from higher pressure operation with correspondingly lower liquid product yields. For this reason, commercial coking is carried out at relatively low pressure (< 340 kPa). Higher yields of gas and light distillates are the result of higher coking temperatures. These increased yields also result in low yields of heavier fractions. Delayed coking is generally carried out with a furnace outlet temperature of $480-520^{\circ}\text{C}$ and a vapour temperature from the coke drums of about 40°C lower due to the endothermic coking reaction.

FIGURE B-1
 DELAYED COKING
 SIMPLIFIED FLOW DIAGRAM



At present, the process is applied to bitumen upgrading in the first oil sand plant, operated by Suncor.

2. FLUID COKING

In fluid coking, coke is deposited on coke particles in a steam fluidized bed. The process is a proprietary process of Exxon Research and Engineering Ltd. and is commercially applied in several units. In the process, shown in Figure B-2, the bitumen is preheated, atomized with steam and sprayed into the fluidized bed at a temperature in the range 275° - 370° C. The bed in the coker is operated at a temperature of about 530° C and yields an overhead product of cracked hydrocarbon vapour and coke deposited on the coke particles in the bed. Heat for the coking reaction is provided by hot coke recirculated back to the coker from the coke heater where it is heated by air combustion of a portion of the coke in a second fluidized bed. Vapour product passes to a fractionator where the different fractions are recovered and an overhead rich gas (C_3 -) produced for plant use.

Produced coke excess to the process requirements is steam stripped to remove hydrocarbon liquids before removal from the plant (Hyndman, 1979).

3. FLEXICOKING

The Flexicoking process is an extension to the Fluid Coking process and is also a proprietary process of Exxon Research and Engineering Ltd.. It involves the addition to the Fluid Coking process of a gasifier (Figure B-3) to gasify residual coke with steam and air to generate

FIGURE B-2
FLUID COKING
SIMPLIFIED FLOW DIAGRAM

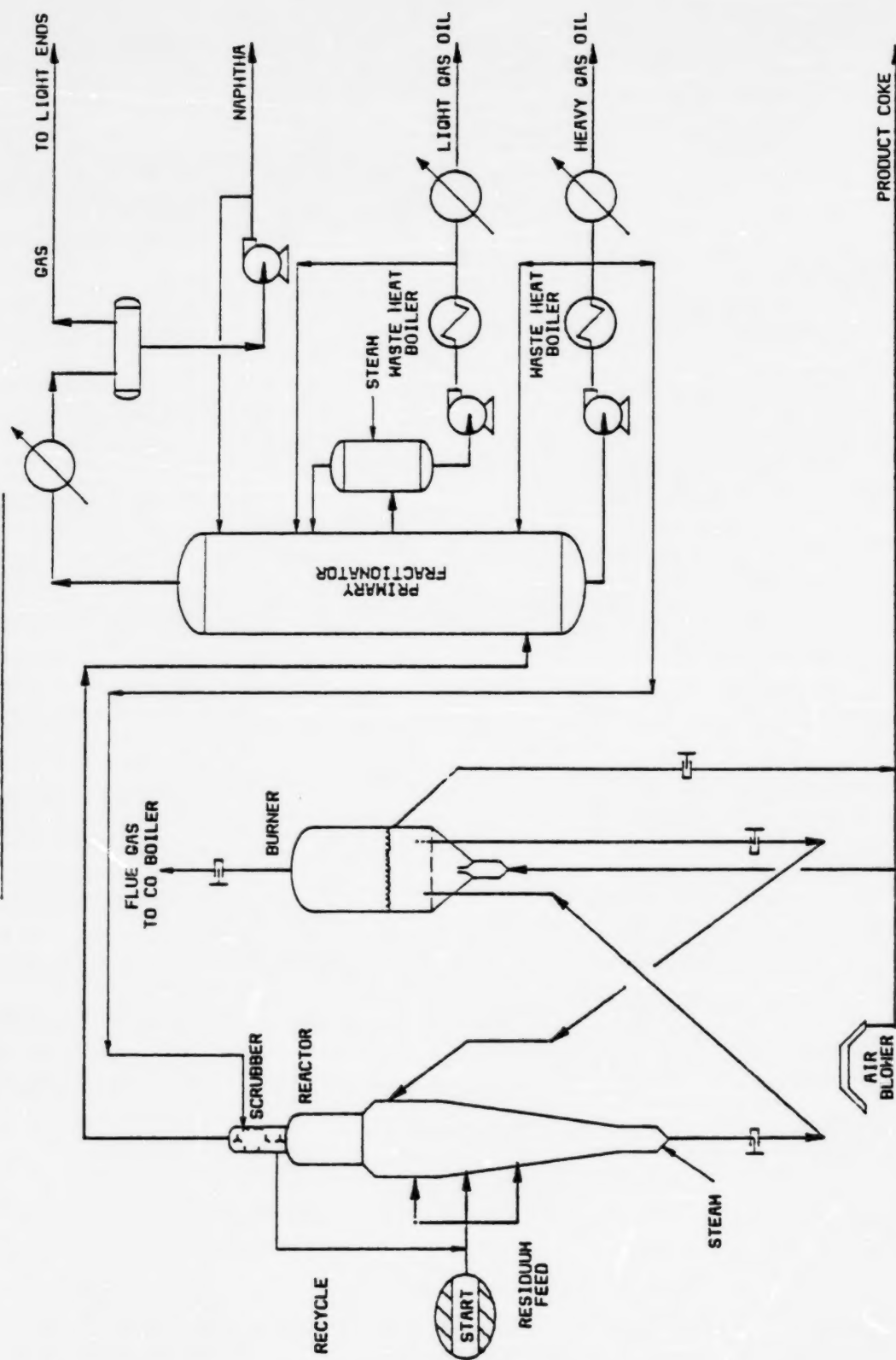
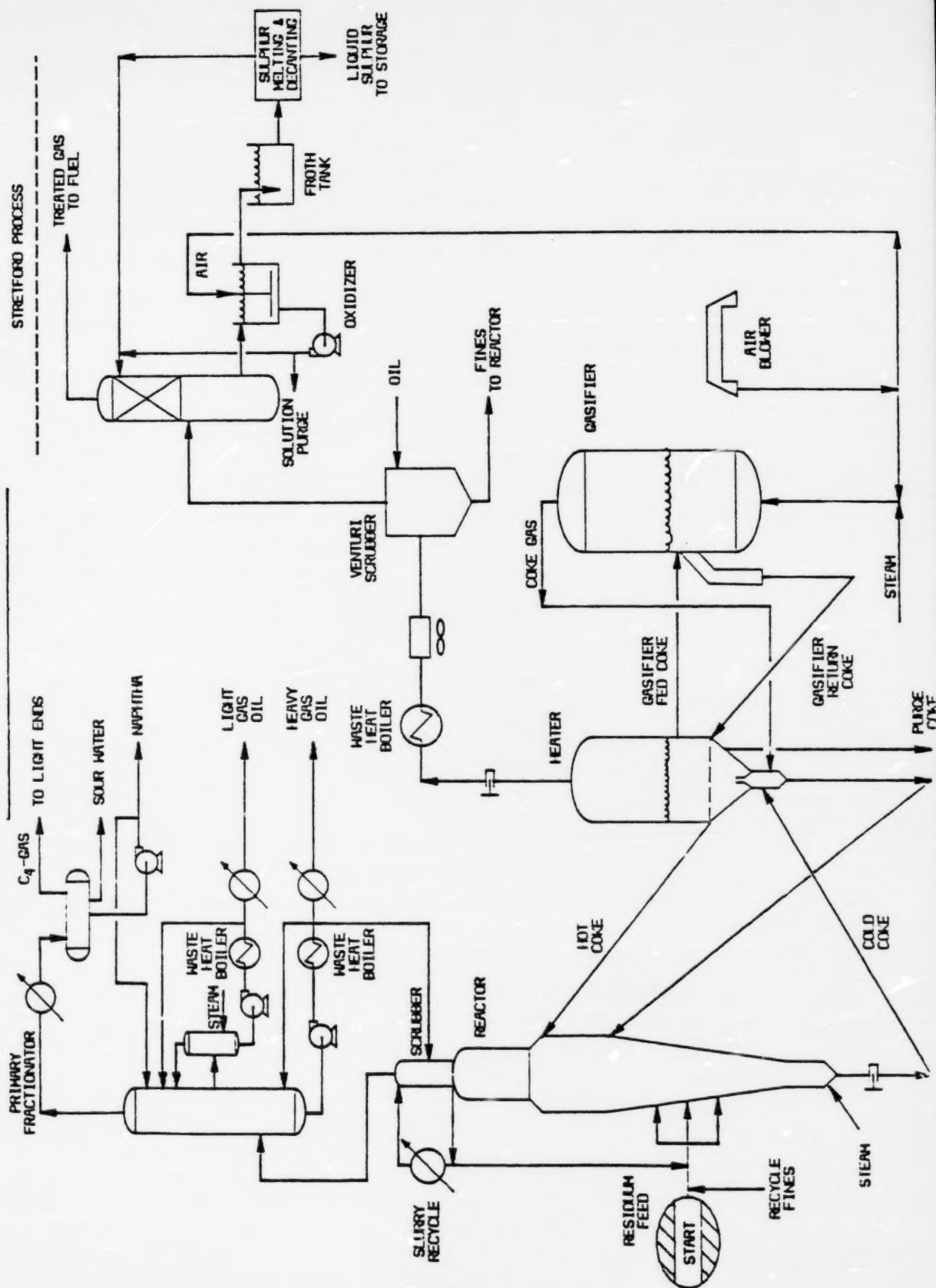


FIGURE B-3
FLEXICOKING
SIMPLIFIED FLOW DIAGRAM



fuel gas usable in the plant. The gasifier used is a fluidized bed unit which gasifies about 95% of the coke produced and recirculates a residual ash steam to the coke heater. The balance of ash components is maintained by withdrawing a purge coke stream from the heater.

The coke stream to the gasifier reacts with steam and air at temperatures from 815° to 980°C , producing a fuel gas composed of CO , H_2 , CO_2 , N_2 , H_2S and steam. The sulphur content of the gas can be removed by any of a number of commercially available processes. This provides a less expensive method of sulphur recovery from the coke than stack gas cleaning which might otherwise be necessary if the coke is used as fuel.

Flexicoking has been applied commercially at a TOA Oil Company refinery in Japan where a $3,330\text{m}^3/\text{d}$ unit is operated. A test was made on Flexicoking of Athabasca bitumen using Exxon's $120\text{m}^3/\text{d}$ Prototype Unit in Baytown in a ten-day demonstration run in 1975. The Alberta Oil Sands Technology and Research Authority, together with Exxon and other industrial participants, commissioned the test in which 1600m^3 topped Athabasca bitumen were processed. The data obtained should provide a good basis for evaluation of the commercial operation of the process.

References: Fuqua (1976)
Exxon (1980)

4. SOLVENT DEASPHALTING

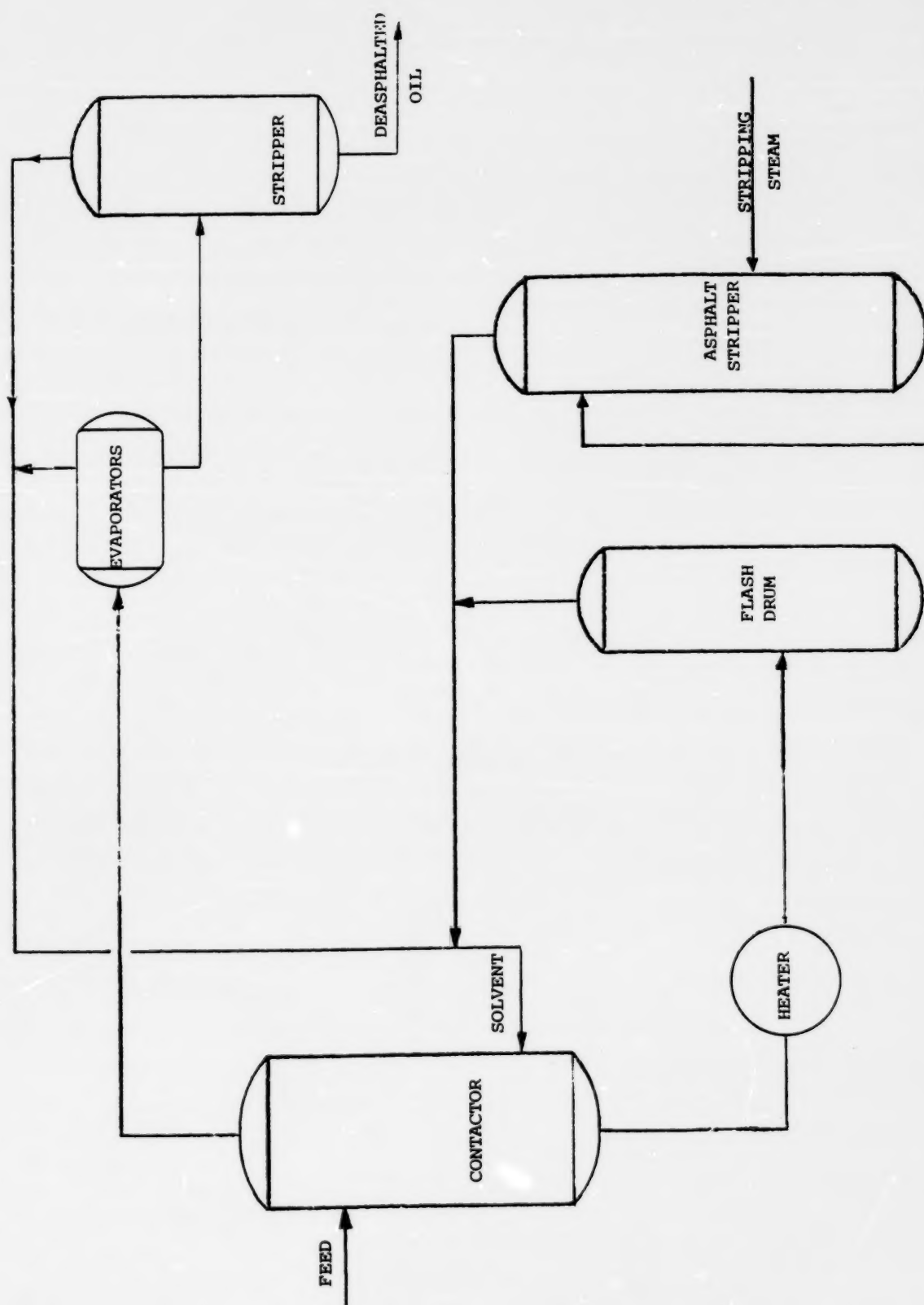
Asphaltenes can be precipitated from bitumen by dilution with petroleum-derived solvents, such as propane, butane and normal pentane. In the process shown in Figure B-4, the feed and solvent are contacted countercurrently in an extraction column from which the deasphalted oil passes overhead along with diluent solvent while the asphaltenes which are precipitated pass out the bottom. Solvent is recovered from both streams by steam stripping and recirculated to the extraction column. Asphaltene is recovered as a solid which normally has high metal and sulphur contents and can be used a fuel - either through intermediate gasification or directly with stack gas cleanup.

The proportion of asphaltenes removed is dependent upon the solvent used with hydrocarbon solvent of higher molecular weight removing less asphaltene (and leaving more lower molecular weight asphaltenes in the extracted oil).

The Residual Oil Supercritical Extraction (ROSE) process is a recently developed form of the solvent deasphalting process. Kerr-McGee Corporation, who licence the process, claim that savings in utilities associated with solvent separation and recovery are realized by operating above the critical pressure of the solvent.

References: Adams (1979)
Perlaký (1979)

FIGURE B-4
SOLVENT DEASPHALTING



5. THERMAL VISBREAKING

Thermal visbreaking is similar to delayed coking in upgrading by thermal treatment but is milder. The feed, as shown in Figure B-5, passes through the furnace and to a soaking drum for the required thermal decomposition to take place. The effluent from the soaking drum is quenched with recycle oil from the fractionator (Hus, 1981).

Thermal visbreaking is characterized by low conversion of high boiling material. It yields a product of lower viscosity than the feed but containing unsaturates such as olefins and diolefins which can polymerize and cause problems in pipelining. The presence of these unsaturates also necessitates segregation of the material from other crudes in a refinery and a separate processing plan.

6. EUREKA

A new coking process which operates semi-continuously is the Eureka process developed in Japan. The process, shown in Figure B-6, involves continuous steam stripping during the coking reaction to yield, as bottom product, a pumpable residual pitch. The process is currently applied in one unit in Japan at a scale of $3,170 \text{ m}^3/\text{d}$ in commercial operation since 1976.

FIGURE B-5
THERMAL VISBREAKING

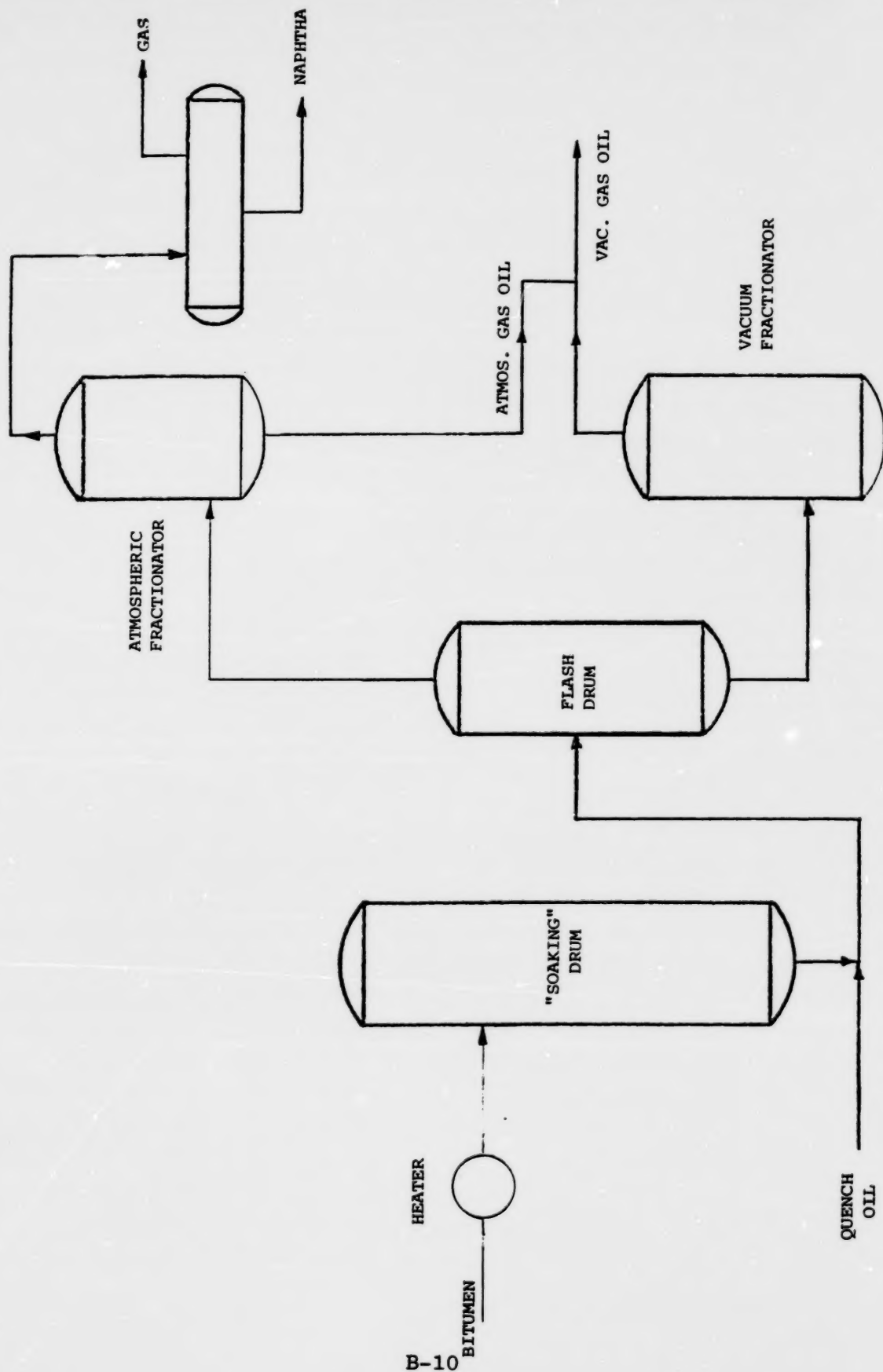
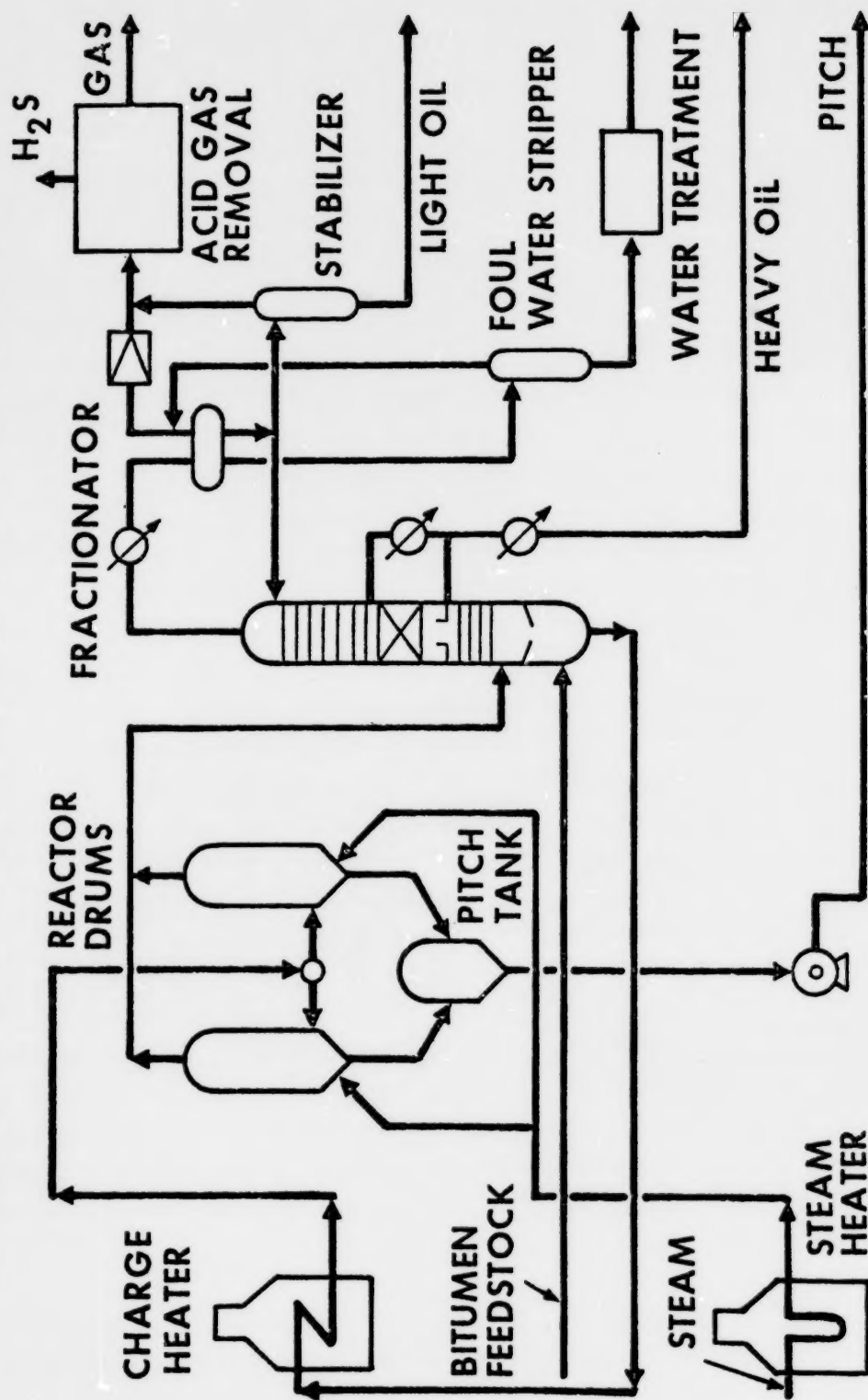


FIGURE B-6

EUREKA PROCESS FLOW SHEET



7. DIRECT COKING

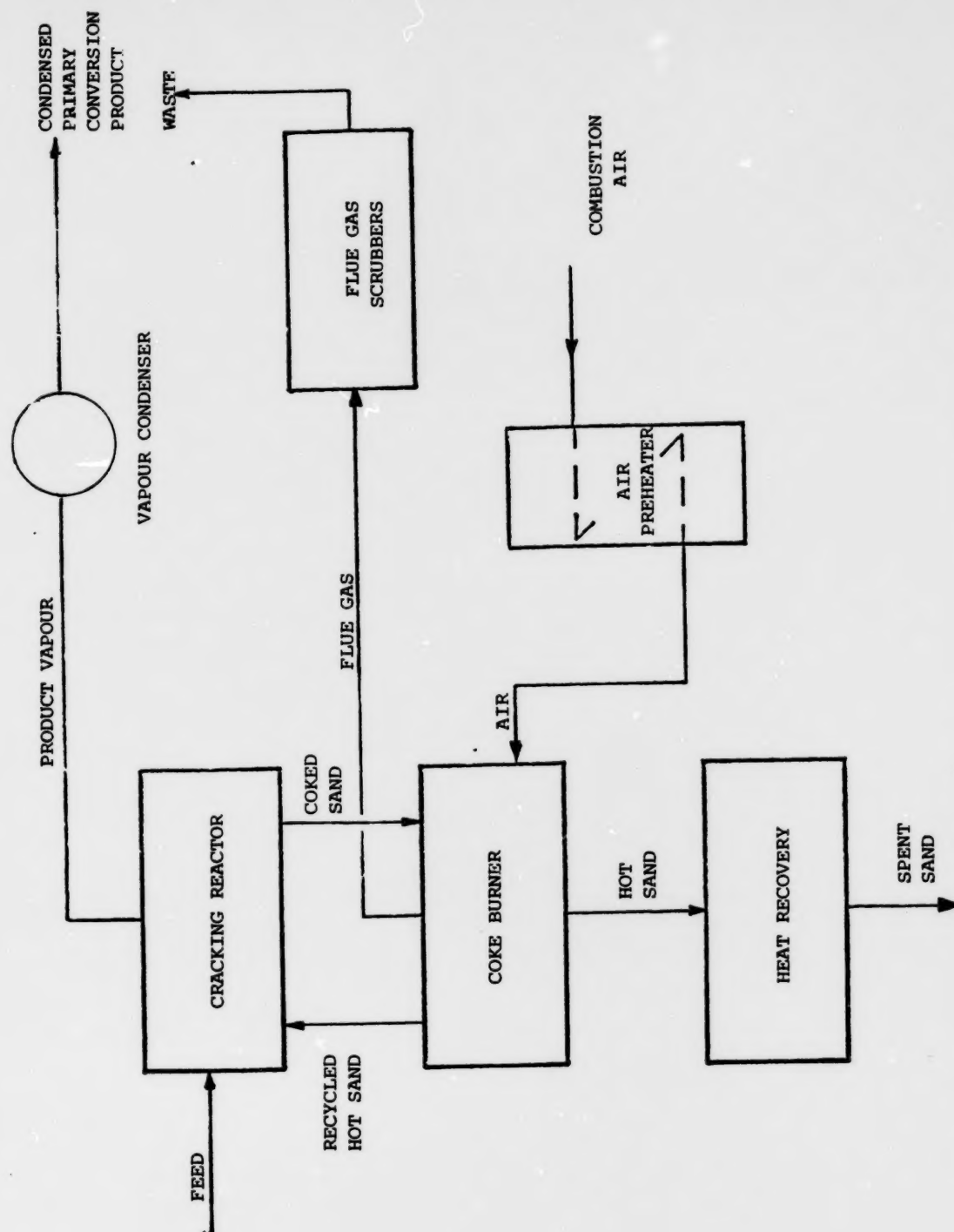
In oil sand processing, the development of a process for thermally cracking the bitumen of oil sand without first removing it from the accompanying sand has been a topic of continuing interest. Such a process would accept raw oil sand and deliver a liquid product of cracked distillate for further upgrading.

The process, shown conceptually in Figure B-7, involves feeding raw sand to a reactor and heating it to cracking temperature (say 7482°C), along with recirculated hot sand, to generate cracked hydrocarbon vapours and sand with coke and residual hydrocarbons. High boiling material ($>527^{\circ}\text{C}$) from the distillate product would be recycled to the reactor or used as supplementary fuel. Heat would be provided to the process by burning a portion of the carbon deposited on the sand and recirculating the heated sand to the reactor. A purge stream of hot clean sand would be withdrawn.

The critical element in the economic operation of the process is recovery of heat from the spent sand tailings. If such heat recovery can be achieved and combined with effective recovery of heat from the flue gas effluent, the process should be promising as it could potentially offer higher energy efficiency than other existing technology.

Direct coking eliminates the separate extraction, froth separation, diluent recovery and primary bitumen conversion processes from existing type plants. It would

FIGURE B-7
DRY DISTILLATION PROCESS



decrease water required for the process and could decrease the size of tailings pond required. Liquid product could still require sulphur removal and hydro-treating.

Two different versions of direct coking are presently being considered --

Lurgi/AOSTRA are studying the use of the Lurgi-Ruhrgas process which carries out the pyrolysis reaction in a screw conveyor and;

UMATAK/AOSTRA are studying the use of a rotary kiln for the process. Figure B-7 would apply to either route.

References: Filby (1980)
Taciuk (1981)
Rammler (1978)

APPENDIX C
HYDROGEN ADDITION PROCESSES

1. CATALYTIC HYDROCRACKING, H-OIL, LC-FINING & VEBA OIL

The H-Oil and LC-Fining process are both derived from an original development by Hydrocarbon Research Inc. and Cities Service and utilize an ebullated bed reactor to contact the feed oil with pelletized hydrogenation catalyst. Fresh catalyst can be added and spent catalyst removed during process operation to maintain the activity level. The H-Oil version of the process is applied commercially and licensed by Hydrocarbon Research while the LC-Fining version was developed further from the original version by Lummus and Cities Service (hence, LC-) and is licensed by Lummus for commercial application. The Veba Oil process on the other hand uses a disposable catalyst in entrained operation with a series of reaction towers.

The catalytic hydrocracking process, shown schematically in Figure C-1, has been widely studied for use in upgrading heavy oil, bitumen and residual stocks, such as atmospheric or vacuum bottoms. This process will yield, with most feeds, a product suitable directly for use in subsequent FCC processing without additional hydrotreating, (Eccles, 1979; Fornoff, 1980; VanDriesen, 1978, 1979).

The catalyst in the H-Oil and LC-Fining reactor (Figure C-2) is maintained in suspension by recirculation of the liquid inventory in the reactor with an internal pump. The high rate of circulation in the ebullated bed provides isothermal conditions within the reactor and avoids hot spots. An additional advantage relative to fixed bed operation is the ability to pass fines from the feed through the reactor without plugging. Operating pressure is generally about 17 MPa.

FIGURE C-1
CATALYTIC HYDROCRACKING

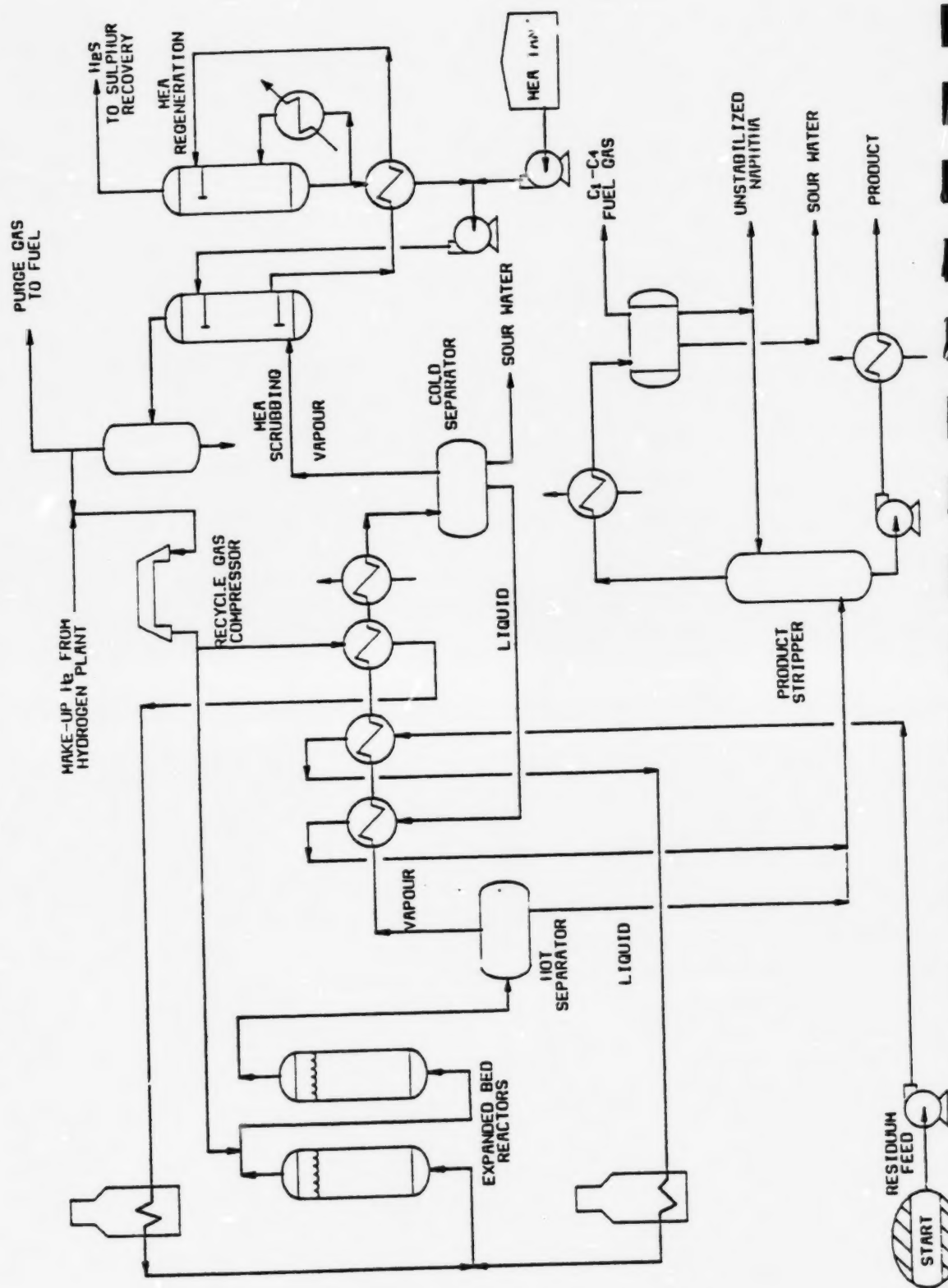
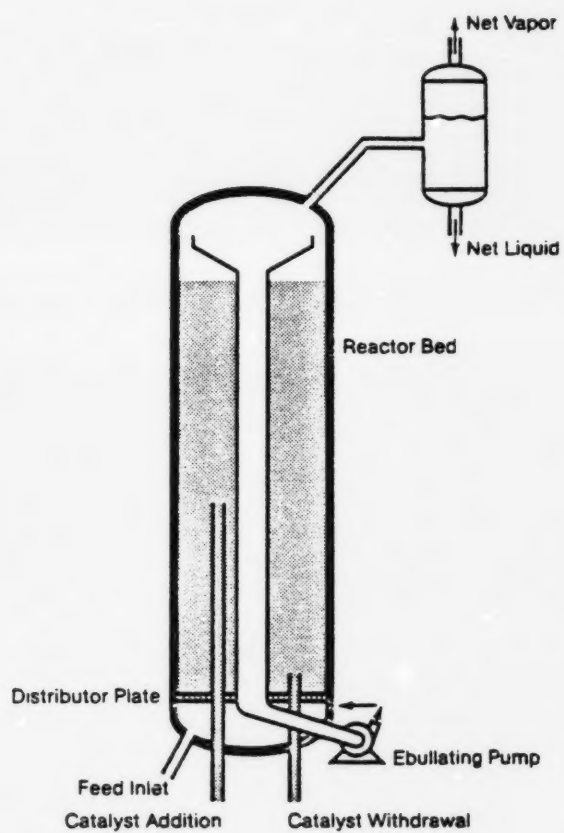


FIGURE C-2
H-OIL REACTOR



Hydrocarbon Research Inc. (HRI) have furnished their commercially operating H-Oil reactors in both designs - hot wall and warm wall with refractory and liner. They now recommend the latter and for the inside of the shell two SS weld overlays.

Depending on the severity of conversion, each train will contain one, two or three primary reactors in series. When upgrading Athabasca type bitumen, one train could process $3185 \text{ m}^3/\text{d}$ (20,000 b/d) with two reactors in series. They would be followed by two vapour/liquid separators and vapour coolers.

The primary reactor vessel is 3.8 m (12'-6") I.D., and 15.5 m (51') length. It is made of $2\frac{1}{4}$ Cr-1 Mo steel (hot wall design) using one SS 347-type weld overlay and in addition, a 150 mm (6") thick refractory (which may be reduced to 100 mm).

A typical $7962 \text{ m}^3/\text{d}$ (50,000 b/d) plant would require two trains, each containing:

- 2 - primary reactors, 3.8 m I.D., 15.5 m high;
 - 2 - effluent separators, 2.4 m I.D., 6 m high;
 - 3 - lockpots for catalyst addition and withdrawal, 1 m I.D., 3 m high;
 - 1 - high pressure slurry letdown pump, 3.3 m I.D., 7.2 m high;
 - 1 - high condensate receiver, 1.2 m I.D., 4.2 m high;
- per plant, two hydrotreaters each for naphtha and gas oil: For a plant total of 20 pressure vessels.

In addition, if partial oxidation is considered for manufacture of hydrogen, two Texaco gasification systems will be used; increasing the pressure vessel total per plant to 25.

A typical plant using Veba Oil's 11,943 m³/d (75,000 b/d) Heavy Oil Upgrading process will contain four parallel trains, three reactors in series, plus two cold separators and one washtower; or, per plant:

- 12 - primary reactors;
- 4 - hot separators;
- 8 - cold separators;
- 4 - washtowers.

Additionally, to prepare the raw product for further processing in conventional refineries, the following are required:

- 1 - naphtha hydrotreater;
- 2 - distillate hydrotreaters;
- 2 - gas oil hydrotreaters -

for a total of 33 heavy wall pressure vessels.

The primary reactor has an I.D. of 2.5 m, is 20-25 m high, has 160-180 mm wall thickness, would operate at 31 MPa and 460-480°C. The vessel could be fabricated from light alloy steel using refractory and SS liner, or could be made in hot wall design using SS material.

The hot separator is of similar dimensions and operating conditions, but only about 10 m high; while the cold sep-

arator is the same, except it operates at about 50°C. The washtower has a diameter of about 1.5 m and operates at 50°.

2. NON-CATALYTIC HYDROCRACKING: CANMET

The CANMET process uses a suspended disposable additive to achieve hydrocracking at moderate pressure and high temperature. The additive prevents deposition of coke in the reactor and permits the process to achieve high conversions of bitumen to distillate with low (relatively) hydrogen consumption (Lunin, 1980; Pruden, 1977).

In the CANMET process, approximately 60% of the sulphur is removed as hydrogen sulphide from the bitumen feed. Thermal hydrocracking of the hydrocarbon in the bitumen produces a range of lighter boiling components and a pitch residue which contains most of the original metal content of the bitumen. The liquid product is flashed to separate hydrogen-rich gas for recycle and liquid components for fractionation to products.

The CANMET process is currently being developed for evaluation of its commercial potential by Petro Canada. A pilot unit is currently being designed for installation in Quebec.

The process has not yet been commercially tested. Published data and personal quotations on required operating pressures would indicate a very broad range, with 15 MPa at the lower end.

Hydrogen is apparently less selectively applied in this process. As a result, desulphurization is lower and the coking tendencies are higher. To control fouling by coke, it may be necessary to use higher operating pressures. This would increase unit capital costs of the primary reactor. All liquid products require second-stage hydrogenation to produce a good quality synthetic crude.

3. GULF HDS PROCESS

The Gulf HDS process is an alternative catalytic hydrocracking route which is based on fixed bed operation. As with other fixed bed processes, it is subject to local overheating due to inhomogeneities in the bed and to catalyst deterioration depending on the impurities in the feedstock and the severity of reaction. Reactor pressures are generally about 16.5 MPa and the nominal operating plan assumes 6-12 months operation between maintenance shutdowns.

In connection with proposals to develop small (3,000 m³/d) upgrading plants (McCann, 1978), the Gulf HDS process has been suggested as a suitable unit. The process would produce a good quality refinery feedstock but would require addition of fuel oil upgrading units or oversizing the HDS unit to permit recycle if no residual fuel market was available.

Reference: Ondish (1979)

4. UOP AURABON PROCESS

The Aurabon process is an adaptation of the RCD Unibon process developed particularly for heavy oil upgrading (Sikonia and Hemler, 1979). The process consists of a hydrogenation section followed by a separation section. In the separation section four streams are generated - a hydrogen rich gas recycle, a liquid recycle stream to the reactor, the product oil or Aurabonate and a drag stream containing the bulk of the metals from the original feedstock. The process developer, UOP, claims that metal accumulation is avoided and catalyst deterioration is minimal in the process. The produced oil or Aurabonate is a good feed for FCC.

5. UNICRACKING/HDS

Unicracking has been developed as a fixed bed, catalytic hydrocracking process similar to the Gulf HDS process. The process has been developed in conjunction with Kellogg to be used with Kelloggs' Heavy Oil Cracking Process, for upgrading of bitumen and residual oil to distillate fuels. The Kellogg HOC process is a type of FCC process which has been developed for use with feedstocks having high metal and asphaltene contents.

The feed and hydrogen are preheated and introduced through a guard reactor into the main cracking reaction. The guard reactor uses the same catalyst as the main reactor to scavenge particulates and matter impurities from the feed (Skripek, 1979).

Recycle gas rich in hydrogen is separated from the product and the product is cooled and stripped to meet vapour pressure specifications.

6. ARCO HDS/FCC PROCESS

The Atlantic Richfield Company operates a pilot scale continuous FCC unit and have studied the processing potential of oil sand bitumen with the unit. Initial tests indicated moderate reductions in sulphur and nitrogen contents of the product from HDS processing and appeared to have potential for FCC feedstock preparation.

7. SHELL MOVING BED PROCESS

Shell has developed an entrained or moving bed modification of catalytic hydrocracking (similar to Veba Oil). Catalyst would be added periodically and the residence time for the reaction would be controlled by reactor sizing and the number of reactors in series.

8. DYNACRACKING

The Dynacracking process is an expanded bed process developed by Hydrocarbon Research Inc. (HRI) which carries out the hydroconversion of residual oil and the gasification of solid residue to produce hydrogen-rich gas in one reactor vessel (Dawson, 1981). The reaction takes place at a pressure of 2.7 MPa and temperatures from 540-980°C.

APPENDIX D
COAL LIQUEFACTION PROCESSES

1. H-COAL PROCESS (CATALYTIC HYDROGENATION)

Developed by Hydrocarbon Research, Inc. (HRI) and Cities Service Oil Company, the original H-Coal Process dates back to 1964. It is essentially an extension of the ebullated bed processing technology originally used to convert heavy oil residues from petroleum into lighter fractions, (H-Oil Process). Early development work was sponsored by the Office of Coal Research, permitting HRI to build a three tons per day process development unit, (PDU), which was used for testing of all the major coals including various eastern bituminous coals and western subbituminous coals, plus Australian brown coal.

Data and information acquired from this PDU was used as the basis for design and engineering of the 600 t/d demonstration plant now operating in Catlettsburg, Kentucky. The sponsorship is provided by the U.S. Department of Energy, and a private consortium comprising the Electric Power Research Institute, (EPRI), Ashland Synthetic Fuels, Inc., Mobil Oil Corporation, Standard Oil Company (Indiana), Conoco Development Company and the Commonwealth of Kentucky.

The H-Coal Process uses a cobalt molybdenum catalyst in an ebullated bed reactor. The process components and equipment are arranged to produce a range of liquid products from heavy boiler fuel to light clean synthetic

oil.

In the process, coal is crushed to 0.25mm, dried and slurried with recycle oil. At a pressure of 20 MPa, the slurry and hydrogen are mixed and preheated and fed to the bottom of the ebullated reactor. The slurry flows upwards in the reactor, maintaining the catalyst in a fluidized state. The catalyst activity is kept within desirable levels by continuous addition of fresh catalyst and withdrawal of spent catalyst. Reactor temperature is controlled by adjusting the preheater outlet temperature, which is typically 340°C to 370°C.

The vapour product from the reactor is cooled and the heavier components are collected as liquid. The gas is sent to the separation unit, where light hydrocarbons, ammonia and hydrogen-sulphide are separated out. The hydrogen rich gas is recompressed and recycled to the slurry mixing plant. Absorbed gases are treated to yield fuel gas, sulphur and ammonia. The liquid stream from the primary condenser is fed to an atmospheric pressure distillation unit, where it is distilled to produce a light distillate and a heavy distillate product.

The overhead products are treated in the distillation unit, while the bottoms product is further treated with a hydrocyclone, or a liquid-solid separator, and vacuum distillation unit. The solid liquid product stream, which contains unconverted coal, ash and oil is fed from the reactor to a flash separator. All

products, liquid or gaseous, can be further refined to marketable products. A portion of the heavy distillate is recycled as the slurry medium. By varying the operating conditions of the H-Coal process, the product slate can be altered. To produce a synthetic crude oil, higher temperature and a higher hydrogen partial pressure is required, and the solid-liquid separation can be carried out via vacuum distillation. If, however, a low sulphur residual oil is desirable, then lower temperatures and pressures in the reactor unit are sufficient, an increased amount of gas will be produced, and less hydrogen consumed. Depending on the type of fuel produced and the type of coal fed to the process, between 400 and 570 Nm³ of hydrogen is required for each ton of coal processed. A major fraction of this hydrogen requirement can be obtained from the gas produced in the process, but additional quantities must be generated from external systems. Approximately 90% of the carbon contained in the coal is converted to a liquid by the process.

Typical yields and properties for the syncrude modes processing Wyodak, Wyoming coal, are shown in Table (D-1), while a simplified process flow diagram is shown in Figure (D-1).

References: Comolli (1979)
Eccles (1980)

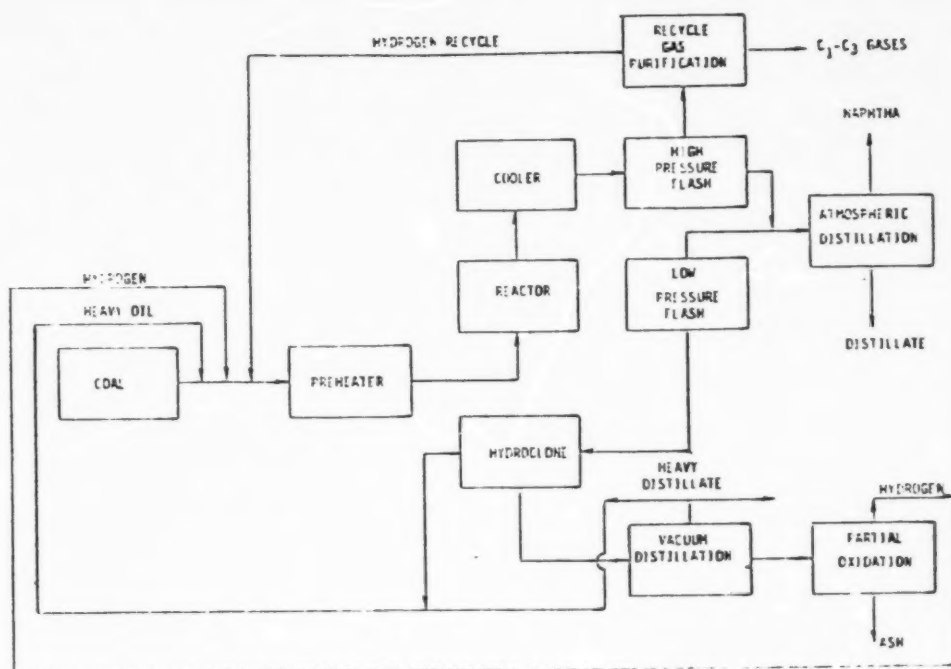
TABLE (D-1)
WYODAK SYNCRUDE MODE
PDU RUN NO. 6

<u>YIELDS</u>	<u>DESIGN</u>	<u>PDU-6</u>
C ₁ - C ₃ W%	9.38	12.35
C ₄ - 204°C	25.77	25.82
204 - 524°C	20.87	18.58
524°C	11.59	11.64
H ₂ O	16.85	16.97
CO, CO ₂ , NH ₂ , H ₂ S	3.97	4.59
ASH	8.28	7.80
UNCONVERTED COAL	8.97	8.50
	<u>105.68</u>	<u>106.25</u>

No evidence of calcium induced deposits.

SOURCE: Eccles et al (1980)

FIGURE (D-1)
H-COAL SYNCRUDE MODE



SOURCE: Comolli et al (1979)

The initial plan of the Catlettsburg demonstration plant consortium was to operate the plant in a so-called boiler fuel mode in 1982. This decision has been reversed in view of the changed market situation, which indicates a great demand for light synthetic crudes with a glut of heavy oils emerging. Consequently, the plant tests will continue to use Eastern coals, but operate in the Synfuel mode.

The plant was shut down voluntarily in April, 1981, after operating continuously for 45 days, its first major long term test period. A failure of feed pumps caused deposition of coke in the reactors. Beginning in late 1981 or early 1982, the plant is to run for about 20 weeks processing Illinois coal, and if successful, will then operate on Wyodak coal.

By the time the test series is complete, DOE will have funded 87% of the estimated \$321 Million program.

Hydrocarbon Research Inc. recommends a warm wall design with refractory and liner for their coal liquefaction reactor. For the inside of the shell, two SS weld overlays are recommended. The refractory is Kastolite of 100 mm (4") thickness. Depending on the severity of conversion, each train will contain two or three primary reactors in series.

A typical $9554 \text{ m}^3/\text{d}$ (60,000 b/d) plant would require three trains, each containing:

- 3 - primary reactors, 3.8 m I.D., 15.5 high;
- 3 - effluent separators, 2.4 m I.D., 6 m high;
- 7 - lockpots for catalyst addition and withdrawal, 1 m I.D., 3 m high;
- 1 - high pressure slurry letdown drum,
3.3 m I.D., 7.2 m high;
- 1 - high condensate receiver, 1.2 m I.D.,
4.2 m high -

per plant, one hydrotreater each for naphtha and gas oil would be required: giving a plant total of 50 heavy wall pressure vessels.

2. NEW GERMAN TECHNOLOGY (CATALYTIC HYDROGENATION) AS
DEVELOPED BY RUHRKOHLE/VEBA

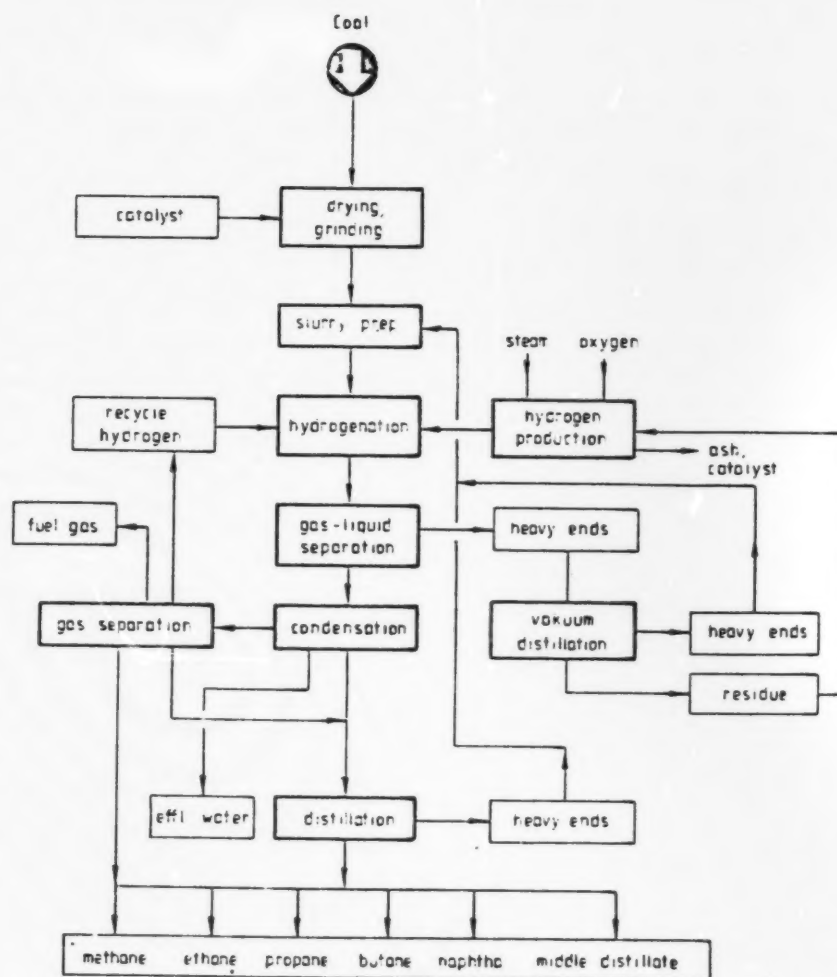
The New German Technology incorporates major improvements over the I.G. Farben Technology, successfully used during World War II in Germany. The main features of the current development are - the reduction of operational pressure from 70 to 30 MPa, still utilizing the same low cost iron oxide catalyst which is termed "red mud".

Coal is ground to -1mm and dried to below 1% moisture by weight. A slurry from the coal and a medium/heavy oil in a 40 to 60 ratio is prepared, followed by wet grinding of the coal to less than .2mm at which time the catalyst is added. The slurry contains approximately 40% by weight of solids. It is then pumped from the slurry preparation tank by high pressure plunger pumps into the pressurized section of the hydrogenation reactors. The hydrogenation step includes high pressure pumps, heaters, reactors in series, separators and oil scrubbers.

Figure (D-2) shows a simplified block flow diagram of this NGT R/V process.

References: Eisenlohr (1981)
Langhoff (1980)
Specks (1980)

FIGURE (D-2)
COAL HYDROGENATION - NEW GERMAN TECHNOLOGY (NGT) 1980

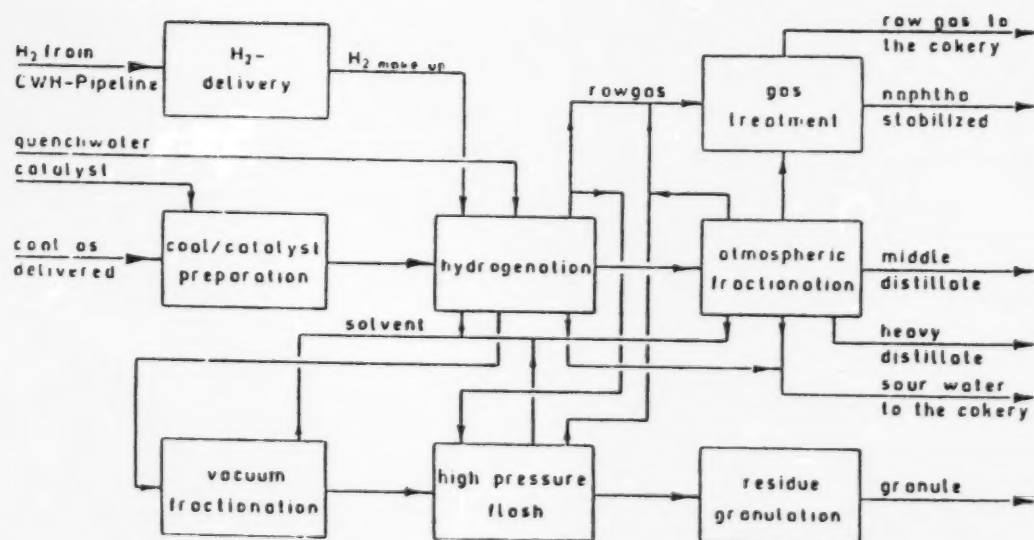


SOURCE: Eisenlohr (1981)

The bottom products from the hot separator will be separated into distillate oil and residue. The latter, containing minerals, undissolved coal and catalyst solids, will be cooled on a steel belt and further processed to supply solid fuel to the coking plant.

A simplified block flow diagram of the 200 t/d pilot plant "Bottrop" is shown in Figure (D-3) while Table (D-2) identifies for the Bottrop plant, the coal and other feedstock requirements and the anticipated products.

FIGURE (D-3)
R/V PILOT PLANT AT BOTTROP



SOURCE: Langhoff (1980)

TABLE (D-2)
FEEDS AND PRODUCTS OF THE PILOT PLANT BOTTROP
(STANDARD CASE)

FEED:

Coal, (maf)	200	t/d
Hydrogen H ₂ make-up	220,000	m ³ /d
Process Water	41.2	t/d
Catalyst (Fe ₂ O ₃)	4.0	t/d
Power	108,000	kWh/d

PRODUCTS:

Gas	61.3	t/d
Naphtha (stab). <200°C	24.4	t/d
Middle Oil 200...325°C	69.0...74.7	t/d
Heavy Oil >325°C	----	t/d
Residue	68.6...74.3	t/d

In the hydrogenation portion, a part of the exothermal hydrogenation heat is recovered in the feed/product heat exchangers. When heated, the coal will swell in the solvent, which increases the viscosity of the slurry reaching a maximum at about 300 to 350°C to be followed by a steep decrease during the chemical decomposition of the coal. Consequently, the secondary heater in the process arrangement is of critical design for the heat transfer rate is lower in the high viscosity range while coking tendencies are increased at this point. After the secondary heater, the heated reaction mix flows upwards through three reactors in series. Following the reactors, a phase separation takes place in the hot separator, where gases and vapours are removed at the top, and liquids and solids are discharged from the bottom. Top outlet products are cooled in the feed/products heat exchanger by water quenching and indirect cooling. Condensates are withdrawn and pumped to atmospheric distillation. The remaining hydrogenation gas is cleaned in an oil scrubber and the resulting gas is used as recycle gas, or discharged as purge gas.

The coal oil derived in the separator section is treated by atmospheric distillation, flash drums, distillation heaters and a top column fractionator for the distillation separation of the coal oil into gasoline and light, medium and heavy oil fractions. A gasoline stabilizer column may also be needed.

A typical 9554 m³/d (60,000 b/d) NGT Coal Liquefaction Plant will contain four parallel trains, three or four reactors in series, plus one hot separator and two cold separators and one washtower; on a per plant basis one would have:

- 12-16 - primary reactors;
- 4 - hot separators;
- 8 - cold separators;
- 4 - washtowers.

Additionally, to prepare the raw product for further processing in conventional refineries, the following are required:

- 1 - naphtha hydrotreater;
- 1 - distillate hydrotreater;
- 1 - gas oil hydrotreater -

for a total of 31-35 heavy wall pressure vessels.

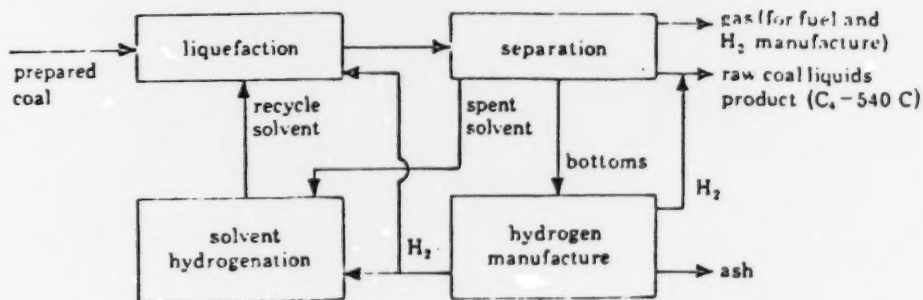
The primary reactor has an I.D. of 2.5 m, is 20-25 m high, has 160-180 mm wall thickness, would operate at 31 MPa and 460-480°C. The vessel could be fabricated from light alloy steel using refractory and SS liner, or could be made in hot wall design using SS material.

The hot separator is of similar dimensions and operating conditions, but only about 10 m high; while the cold separator is the same except it operates at about 50°C. The washtower has a diameter of about 1.5 m and operates at 50°C.

3. EXXON DONOR SOLVENT PROCESS (EDS) - SOLVENT EXTRACTION

The Exxon Donor Solvent Liquefaction Process uses the reactions with the hydrogen donating solvent, and the reactions with molecular hydrogen. A simplified flow-sheet for EDS Process is shown below.

FIGURE (D-4)
SIMPLIFIED BLOCK DIAGRAM OF THE EDS PROCESS



The typical characteristics of the EDS Process include making maximum use of petroleum refining technology; applying it to a wide range of coals - from lignite to bituminous; producing a variety of liquid products suitable for a variety of end uses; and, upgrading of products by using conventional petroleum refining technology to relatively low sulfur, oxygen and nitrogen contents.

The key feature that differentiates the process from others under development is the separate solvent hydrogenation step. In the hydrogenation unit, being a simple trickle bed reactor, which contains conventional petroleum hydrogenation catalysts, solvent which has donated its hydrogen during liquefaction is re-hydrogenated for recycling to the liquefaction reactor.

Throughout the fifteen years of research into the process, Exxon has tested a variety of bottoms processing routes. As there will always be a residual carbonaceous material (bottoms) that cannot be recovered in the fractionator, it is imperative to maximize the efficiency of the bottoms recovery process in order to achieve a high efficiency liquefaction process. The most favourable options for the utilization of the bottoms fraction involve its conversion to both fuel gas and some other product. When the proprietary Exxon Flexicoker System is employed, additional liquid products are recovered. However, if the more common gasification system is employed, then the products will be fuel gas and hydrogen.

Typical products from the EDS Liquefaction Process are summarized in Table (D-3).

TABLE (D-3)
EDS PRODUCTS AND THEIR DISPOSITION

<u>STREAM</u>	<u>DISPOSITION</u>	<u>YIELD % OF LIQUIDS</u>
C ₄ -177°C Naphtha)	(Motor Gasoline,) (Chemicals)	48-80
177-204°C Distillate) 204-399°C Solvent)	(Jet Fuel,) (Turbine Fuel,) (Home Heating Oil,) (Fuel Oil Blendstock)	10-30
399-538°C Vacuum Gas Oil ..	Fuel Oil Blendstock	10-30
Coker Gas Oil) Scrubber Liquids)	Fuel Oil Blendstock	

The proportions of the total product in each category and their properties depend, of course, on process configuration and feedstock coal. Note that the yield in Table (D-3) is given in percentage of liquids, which typically, in the EDS process may range from 55 to 65% of total moisture and ash free coal fed.

Exxon's 200 t/d demonstration plant of the EDS Process in Baytown, Texas, recently completed 11 months or 3,900 hours of tests with Illinois bituminous coal, and is now in the process of testing Wyoming subbituminous coal, which will be followed by Texas lignite tests. The objective of all the test programs with coal is to improve the liquid yields over the earlier version using Flexicoking only for bottoms processing. It appears that Exxon now believes that when a portion of the heavy oil residues are recycled back to the liquefaction reactors,

as is the common feature in the German processes and in the H-Coal Process, the utilization of retrieveable carbon and hydrogen can be increased significantly.

For this project, DOE is funding 48% of the U.S. \$347 Million, while the balance is being provided by seven sponsors:

- . Exxon Company U.S.A.;
- . Phillips Company;
- . ARCO Coal Company;
- . Electric Power Research Institute (EPRI);
- . Ruhrkohle AG;
- . Agip S.p.A;
- . Japan Coal Liquefaction Development Company.

References: Epperly (1979)
Epperly (1981)

4. Solvent Refined Coal (SRC)

The solvent refined coal process was initiated in an effort to provide a higher quality, solid boiler fuel from high sulphur coal by carrying out a minimum level hydrogenation to produce a solid lower in sulphur and ash. This was accomplished, but changing market trends during the development lessened demand for the product and pointed towards a higher degree of hydrogenation to generate a liquid fuel. This, too, was accomplished and large scale demonstration plant designs were drawn up for both modifications. The processes were differentiated as SRC-I and SRC-II.

SRC-I, the solid fuel modification, has been developed by Southern Company Services and Wheelabrator-Frye and is still progressing towards a demonstration plant. SRC-II was being developed by Solvent Refined Coal, Inc. under contract to the U.S. Department of Energy and international interests, but has now been discontinued.

Both processes involved mixing pulverized coal with recycle liquid in a mixing tank and passing the slurry through a preheater into a reactor under a hydrogen atmosphere. For SRC-I, the reactor temperature and pressure are 435°C and 12 MPa, while for SRC-II, typical conditions are 460°C and 14 MPa.

Pilot plant testing of both modifications was carried out in two separate installations - a 50 t/d plant at Fort Lewes, Washington, operated by Gulf Oil Corp., and a 6 t/d plant operated by Catalytic Inc., at Wilsonville, Alabama.

References: Jackson (1981)
Freel (1981)
Rector (1981)

5. CS/R Hydropyrolysis

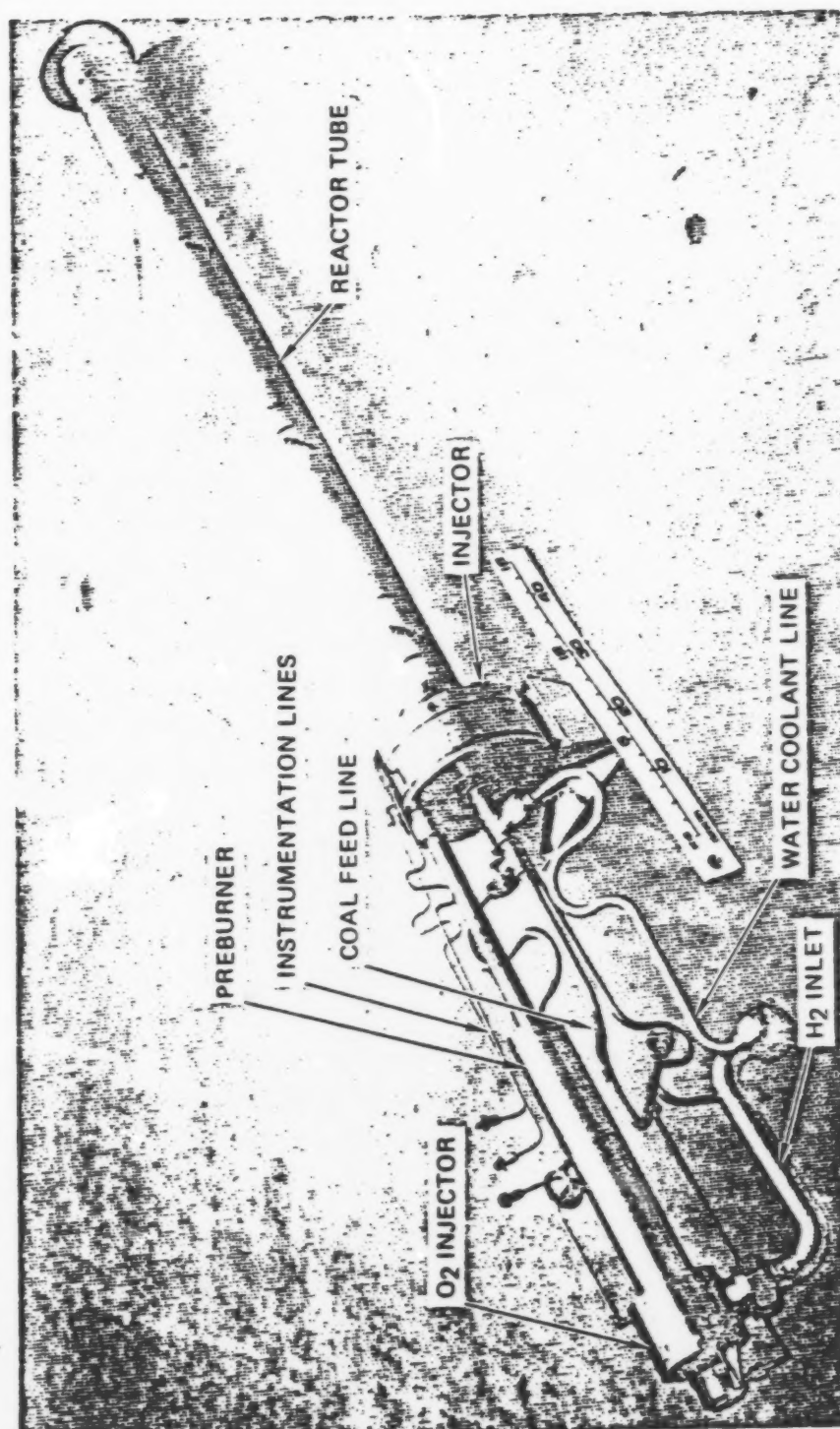
The process is being developed jointly by Cities Service Research and Development Company and Rockwell International (hence CS/R) to pyrolyze coal for very short residence times in a hydrogen atmosphere. The feed coal ground to <50 mesh and dried will be pressurized in lock-hoppers, and carried by nitrogen to the reactor where it is mixed rapidly with heated hydrogen to achieve the rapid pyrolysis. Reactor temperatures will be about 900°C if gas is to be the major product, or 700°C if liquids are required with the corresponding pressures being 8 MPa and 13 MPa. Target residence times are 1.5 seconds for gas product and 0.8 seconds for liquid product.

While the process is not developed to commercial stage as yet, projected commercial units would process about 5,000 t/d (dry basis) of coal and generate 1,300 t/d of liquid products, about 60% of which would be heavy oil with the remainder split between light oil and BTX. Char production would be about 2,000 t/d.

The size of the hydropyrolysis reactors is not known, but they are not overly large as the process is characterized by a high mass flux. Some idea of the scale is given by Figure 5-1, which shows the 1 t/h reactor used by Rockwell for preliminary testing.

Reference: Oko (1979)

FIGURE D-5
1 T/H REACTOR



6. Fischer-Tropsch Synthesis

The production of liquid hydrocarbons from synthesis gas has been developed in two variations by the only company using it - Sasol in South Africa. The two variations are a fixed bed reactor (Figure D-6) which produces a heavier, more paraffinic slate of products, and a fluidized bed reactor (Figure D-7) which produces a more aromatic and lighter slate of products. These reactors are, respectively, the Arge reactor, which was developed by Lurgi in Germany, and the Synthol reactor, which was developed by Kellogg in the United States. Sasol operates both reactor types at their first plant, Sasol I, which has operated since 1955 at Sasolburg, and Synthol reactors at their second plant, Sasol II, operating at Secunda since 1981. A third plant, Sasol III, also at Secunda, is scheduled to go on stream in 1983, also using Synthol reactors exclusively.

The synthesis reaction is strongly exothermic and one of the design problems has been the removal of heat at a sufficiently high rate to maintain uniform reaction conditions. In the fixed bed reactor, the catalyst tubes are cooled by circulating water/steam on the shell side, while the fluidized bed reactor is cooled by, in the latest modification, helical coils immersed in the bed. (Figure D-7 shows an earlier modification which involved a tube bundle immersed in the bed).

The Arge reactor shown in Figure D-6 operates at 2.6 MPa and 232°C and involves passing the synthesis gas down

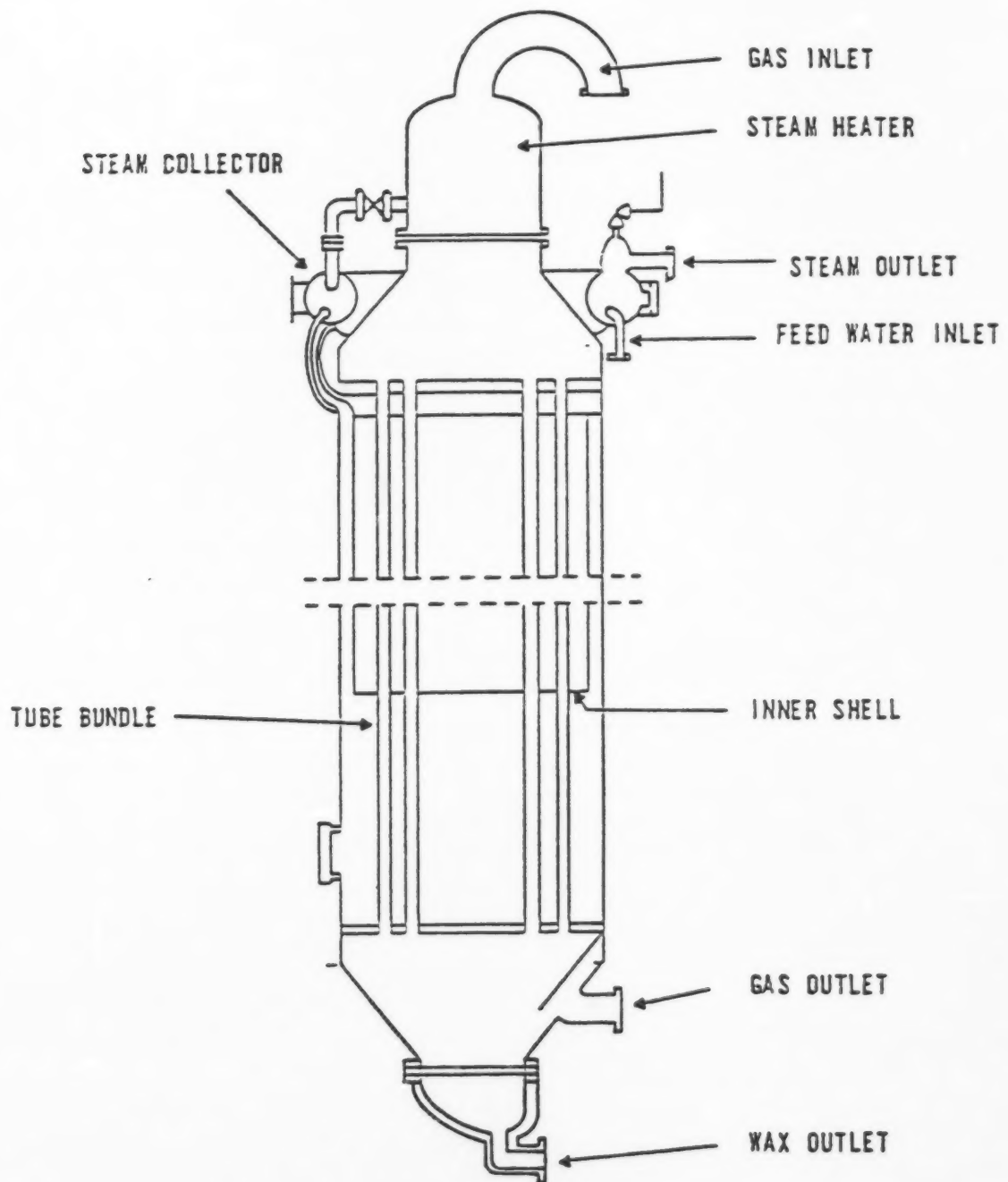


FIGURE (D-6)
ARGE REACTOR

SOURCE: Pay (1981)

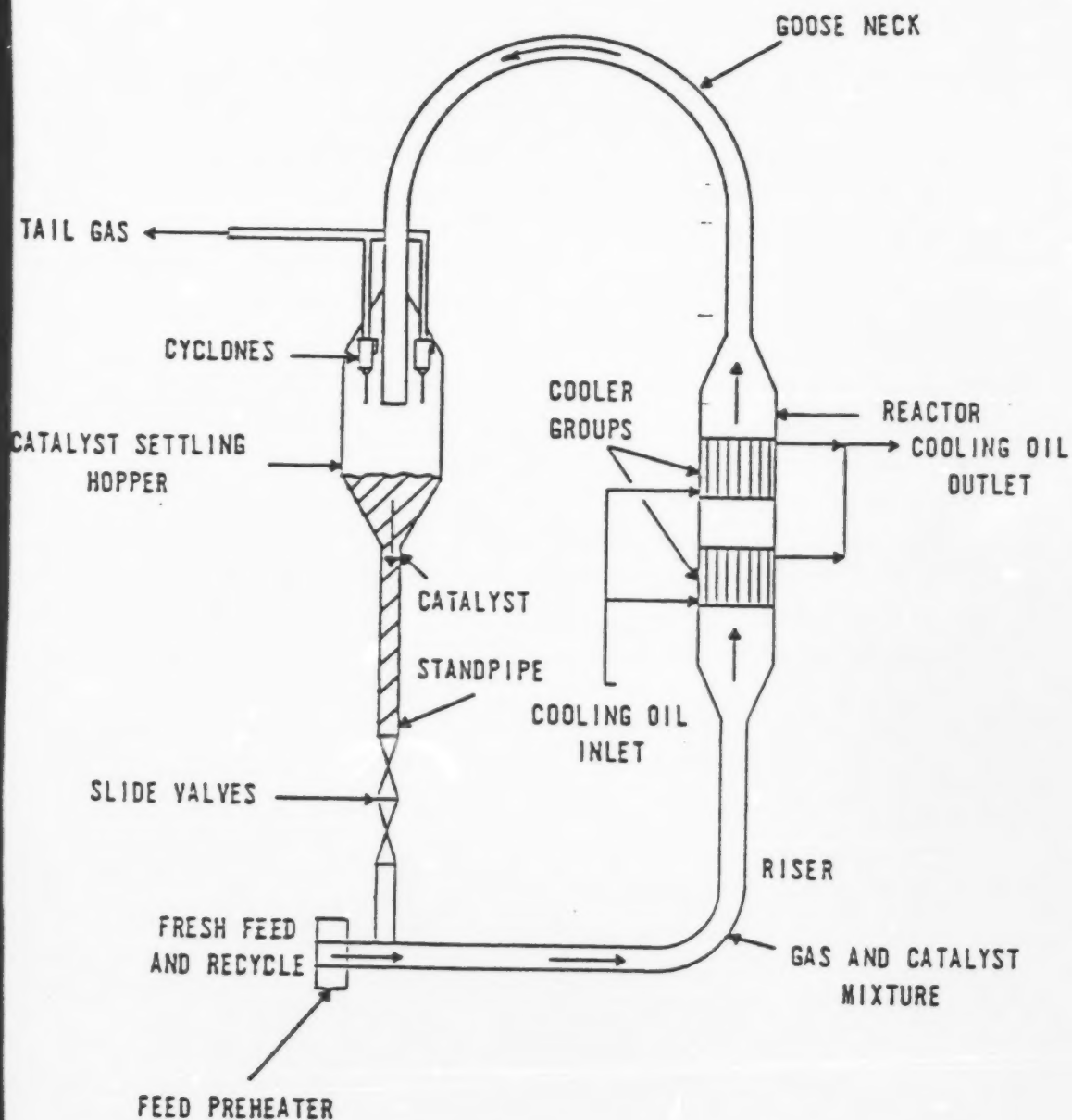


FIGURE (D-7)
SYNTHOL REACTOR
SOURCE: Pay (1981)

through the catalyst beds in the reactor and condensing the products from the tail gas. A portion of the product gas is recycled and mixed with fresh synthesis gas to form the reactor feed. The Arge reactors at Sasol I are 2.95 meters in diameter and 12.8 meters long and the catalyst is contained in 5cm diameter tubes. The pressure differential across the tubes is adjusted by the back pressure on the shell side steam generation. These reactors each process approximately $24,000 \text{ m}^3/\text{h}$ of fresh synthesis gas to give about 20,000 tons of product per year.

The Synthol reactor shown in Figure D-7 operates at 2.2 MPa and 330°C . The feed synthesis gas mixed with recycle gas is heated by catalyst recycle and flows with the catalyst entrained through the reactor. The catalyst is removed by cyclone at the gas outlet and falls into the hopper for re-entrainment. Again, a portion of the product gas is recycled from downstream of the product condenser. The newest Synthol reactors, those in Sasol II at Secunda, are 3 meters in diameter and 75 meters high and process about $325,000 \text{ m}^3/\text{h}$ of fresh feed gas to give $1115 \text{ m}^3/\text{d}$ (7,000 bbl/d) of liquid product.

References: Hoogendorn (1977)
Hoogendorn (1981)
Naude (1981)
Pay (1981)
Swart (1981)

APPENDIX E
COAL GASIFICATION PROCESSES



Lurgi Gasifier

The Lurgi gasifier which is shown in Figure E-1 is the only pressurized gasifier widely used at present. It consists of a steel pressure shell with a second shell jacketing it to form a chamber for water cooling and steam generation. Gasifier pressure is in the range 20-30 MPa (20-30 atm), while the temperature ranges from 500°C at the exit to about 1200°C for the combustion zone. The product gas from a Lurgi gasifier contains pyrolysis products from the fuel as well as the products from combustion of the fuel, and is generally scrubbed with water before further processing. The gas and condensed gas liquor are then separated prior to pressure reduction.

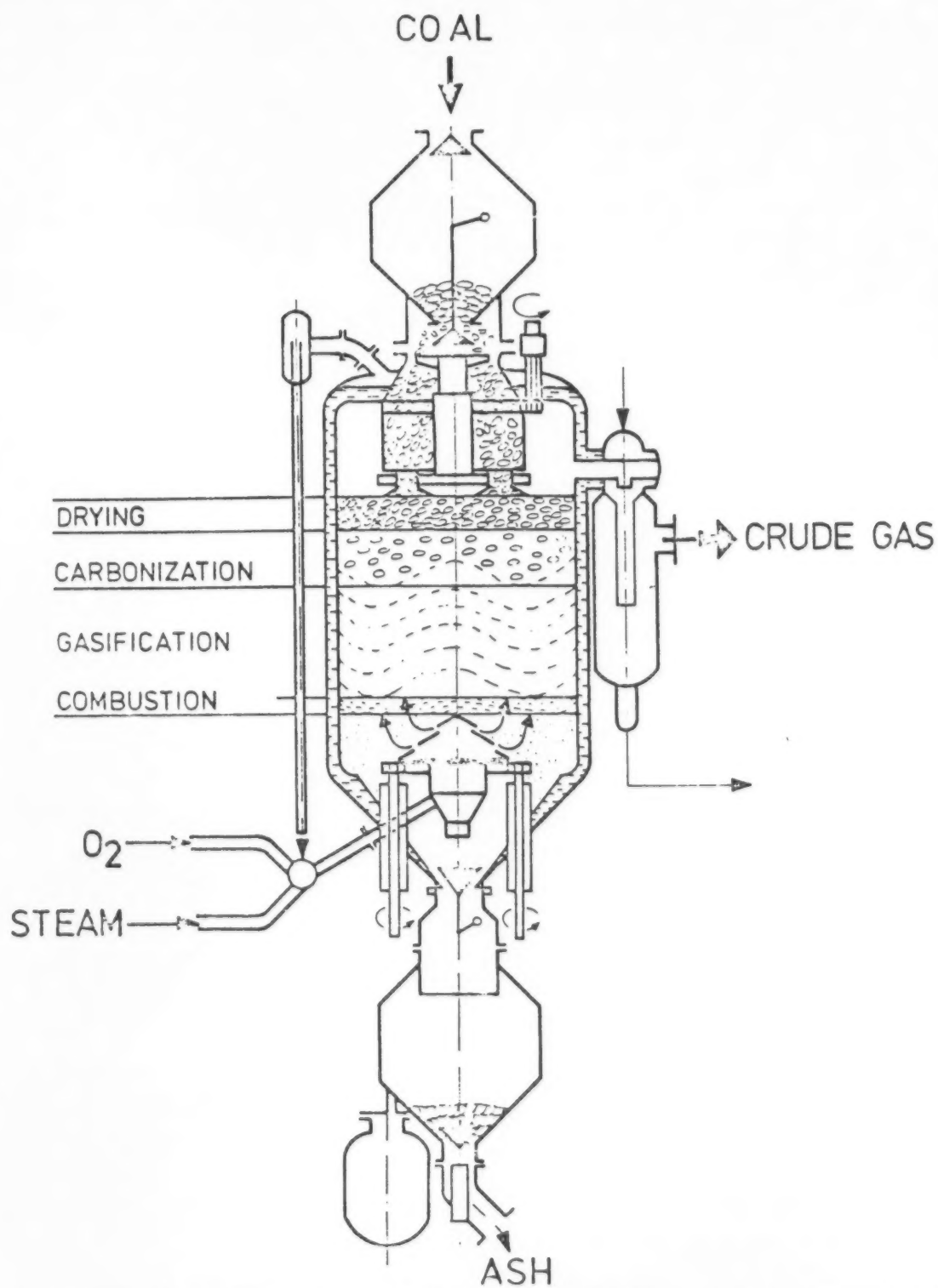
In the Lurgi gasifier, coal is introduced by gravity through a lock-hopper and distributed mechanically across the top of the charge. Gasifying agent - oxygen and steam - are introduced at the bottom and pass upward countercurrently to the coal charge. The coal as it descends from the top of the charge is sequentially dried, carbonized, gasified and the residual char burned as it moves downward. The gasification rate is controlled by the rate of ash removal and the feed rate of gasifying agents. Ash is removed dry through a lock-hopper at the bottom of the reactor. Crude product gas is removed at the top.

The largest Lurgi gasifiers in commercial operation are the Mark IV units used in the Sasol II and III plants in South Africa. These have an internal diameter of 3.85 meters and generate approximately 50,000 m³/hr of raw gas containing

about 56% CO + H₂, 32% CO₂ and 9% CH₄ with the remainder being C₂+, N₂ and H₂S. The gas composition "seen" by the gasifier will be diluted by about 40% unreacted steam. Steam is used in excess to maintain the temperature in the gasifier below the ash fusion temperature of the fuel.

The Sasol II plant uses 36 Mark IV Lurgi gasifiers to produce about 1,100,000 m³/hr pure gas with CO₂ greatly reduced from which approximately 1.5 Mt/d of transportation fuels (about 34,000 bbl/day) are synthesized.

References: Pay (1981)
Elgin (1974)
Rudolph (1975)



(LURGI)

LURGI GASIFIER

FIG. E-1

BGC-Lurgi Gasifier

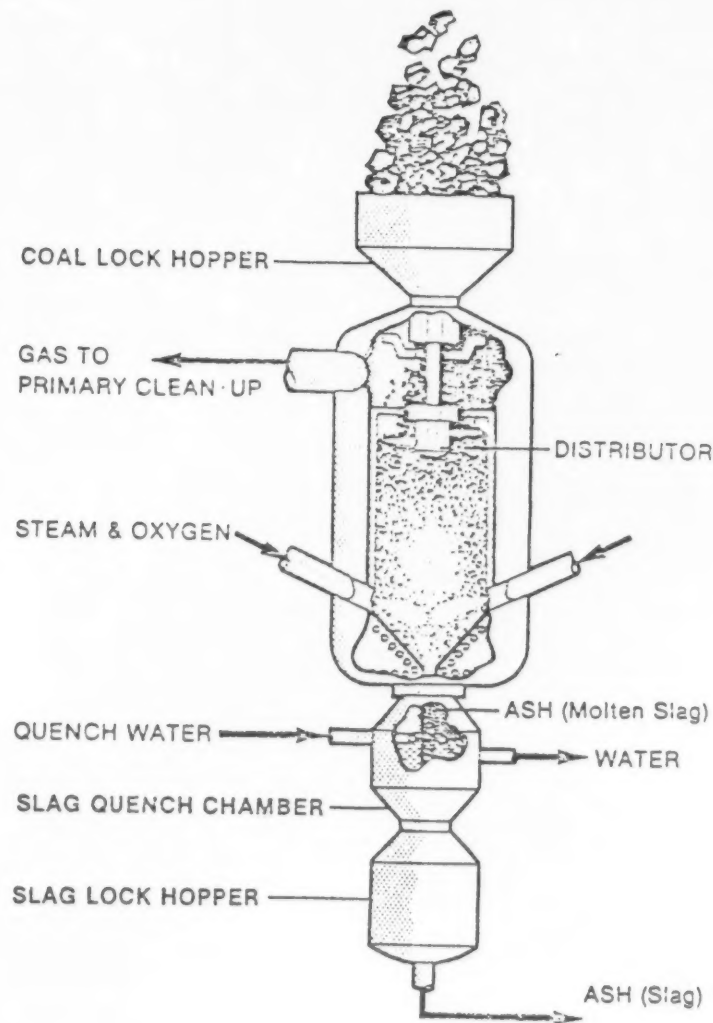
The BGC modification of the Lurgi reactor was carried out to eliminate the restriction of gasification rate in the normal Lurgi caused by the limitation of the temperature to maintain dry ash discharge. The conventional Lurgi is lined with refractory to enable the decrease in steam rate and higher operating temperatures accompanying slagging operation. The BGC-Lurgi gasifier is shown in Figure E-2.

The gasification process in the BGC-Lurgi gasifier is identical to that described for the Lurgi reactor, but less steam is added with the oxygen as gasifying agent and the bottom temperature is higher, melting the residual ash to produce a molten slag which is "tapped" into a quench water bath and removed by a lock-hopper.

This gasifier has not been used commercially, but has been tested on a commercial scale unit - one of the Mark II models which was 2.67 meters in diameter. This was lined down to about 1.83 meters with refractory and, despite having only about one-half of the cross-sectional area, gasified about twice as much coal as the dry ash units. The increase in specific reaction rate (tons of coal/hour/square foot of reactor cross-section) is approximately by a factor of 4 and will have a significant effect on the size of reactor required for a given throughput and the number of gasifiers required for a given service.

Because of the decreased steam reacting, the hydrogen content of the product gas is lower than with the conventional Lurgi and the CO_2 is lower because of the higher gasification temperature. The product gas from prairie subbituminous

FIGURE E-2
BRITISH GAS/LURGI SLAGGING GASIFIER



coal will contain about 88% $H_2 + CO$, 3.5% CO_2 and 7.5% CH_4 . No higher hydrocarbons are produced in the gas and N_2 and H_2S form the balance. The water content of the product gas is low and about all of the steam feed is decomposed. The tar components exiting the reactor and removed by scrubbing are recycled to the reactor - either through tuyeres or as a top spray to lessen dust carryover.

Reference: Sharman (1980)

Davy Winkler Gasifier

The Davy Winkler or Pressurized Winkler gasifier operates at 0.4 MPa and a temperature of about 1000°C. There are presently Winkler gasifiers in commercial operation at elevated pressures, but not at this level. These gasifiers are potentially interesting because of the increased throughput possible with pressurized operation as well as the decreased compression costs for product gases and the smaller volumes required for downstream gas processing.

The pressurized Winkler gasification process involves transfer of coal to reactor pressure through a lock-hopper which feeds, either directly or through an intermediate holding tank, a screw conveyor which injects it into the fluidized bed. Gasifying agents, steam and oxygen, are used to fluidize the coal particles (-10mm) and the approximate mix is used to maintain the reaction temperature below the ash fusion temperature so that fluidization can be maintained. Ash rich bed material is removed continuously by a cooled screw conveyor at the bottom of the gasifier. Product gas, along with entrained particulates, pass overhead.

The reactor is a carbon steel shell lined with refractory brick, but not cooled. Refractory thickness is selected to avoid condensation inside the shell. Coal is raised to reactor pressure with a lock-hopper from which it is transferred to the reactor by screw conveyor. A similar system is used in reverse to remove ash from the gasifier. Product gas is passed first through a cyclone to remove entrained particulate matter.

The Davy Winkler gasifier, like the original Winkler, is not effective in gasifying low volatility coals and has been used for reactive coals only. With prairie subbituminous coal, it would be expected to yield a product gas containing about 76% $H_2 + CO$, 19% CO_2 and 3% CH_4 . Conversions are limited by the carbon content of the bed material removed as ash.

Capacity of the Winkler gasifier operated at 0.4 MPa is approximately 113,000 m^3/hr for a coal feed of 1500 t/d. This unit would be about 4.3 meters in diameter (I.D.), which would require a shell of about 4.8 meters in diameter, and about 18 meters high.

References: Bailey (1979)
Bogner (1981)

High Temperature Winkler - (HTW) Gasifier

The HTW or Rheinbraun gasifier is another modification of the original Winkler design aimed at obtaining more effective gasification by operating at elevated pressure, but it is aimed at pressures in the 1 MPa range. The HTW gasifier has been operated on a pilot plant scale at a test plant near Cologne which has a capacity of 1 t/h. The gasification temperature is expected to be about 1100°C.

The gasification process in the HTW gasifier is similar to that described for the Davy Winkler with the exception that the ash accumulating at the bottom of the gasifier is discharged directly by lock-hopper rather than removed by screw conveyor.

The HTW gasifier is a cylindrical, refractory-brick lined reactor equipped with a water jacket as a safeguard against refractory deterioration. It is estimated that a 5.5 meter (O.D.) gasifier would be capable of producing 150,000 m³/hr of gas.* The HTW reactor does not produce a gas with higher CH₄ content than the Davy Winkler as the effect of higher pressure is balanced by the influence of higher temperature, so that the CH₄ content is about the same - 3%. The higher temperature does lead to a decreased CO₂ content and an increased CO content. The product gas from subbituminous coal would contain about 87% CO + H₂ and 9% CO₂ as well as the 3% CH₄. The produced particulates are removed with cyclones and the recovered carbon recycled to the gasifier. The gasifier system is shown in Figure E-3.

*Such a gasifier would be about 23 meters high.

References: Franke (1979-1)
Franke (1979-2)

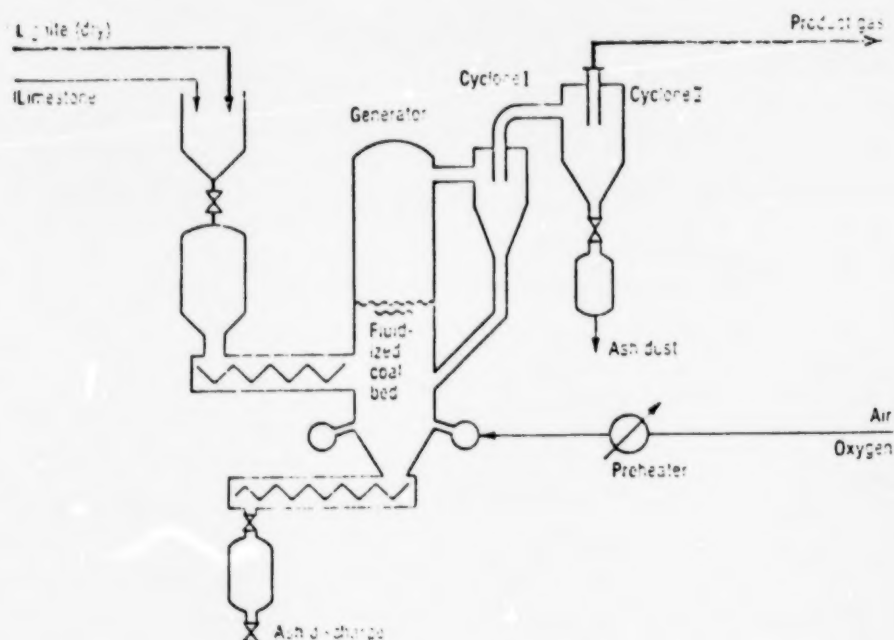


FIGURE E-3
FLOWSHEET OF THE WINKLER HIGH-TEMPERATURE
GASIFICATION ACCORDING TO THE RHEINISCHE
BRAUNKOHLENWERKE AG PROCESS.

Texaco Gasifier

In the Texaco gasifier, the pulverized feed coal is slurried with water and pumped to the reactor. The reactor is composed of two stages - an upper stage lined with refractory into which the slurry is atomized along with oxygen, and a lower stage containing a water quench bath for collecting the slag particles. The gasifier operates at a pressure of 3.5 MPa and a temperature of 1500°C. The Texaco gasifier evolved from a unit used for partial oxidation of residual oil (with pressures up to 8.3 MPa) but the largest coal based units are experimental units, operated by TVA at Muscle Shoals, Alabama and Ruhrkohle and Ruhrchemie at Oberhausen - Haltern, Germany, both of which can gasify about 8 t/h of coal.

In the Texaco gasification process, the pulverized coal slurried in water is injected into the top of the gasifier with the gasification agent, oxygen, and the water evaporates to give a co-current, downward flowing suspension of coal in gas. The gasification of the coal takes place progressively as the particles descend with the heat for the carbon steam reaction being supplied by coal oxidation. Below the refractory nozzle separating the two stages, product gas is removed and the ash continues into the water quench bath below. The ash is removed as particles of slag through a lock-hopper.

The composition of gas produced by gasification of subbituminous coal in a Texaco gasifier is expected to be 85% CO + H₂ and 13% CO₂ with the balance being N₂, CO₂ and H₂S. Because of the high gasification temperature, no tars or oils are produced but there is a carryover of unreacted carbon and flyash and a reasonably high unreacted water content.

The Texaco gasifier is the most advanced towards commercialization of the high pressure, entrained gasifiers, possibly as a result of its history in the gasification of residual oils.

It is included in, for example, a plant under construction at Kingsport, Tennessee by the Tennessee Eastman Company, to produce acetic anhydride and other chemicals from feedstock coal. The Tennessee Eastman plant will include two gasifiers, each of which is rated at 900 t/d coal feed and will use locally mined high sulphur coal.

References: Alves (1981)
Cornils (1980)
Cornils (1981)
Robin (1978)

Shell Gasifier

The Shell gasifier is a development from the original Koppers-Totzek gasifier modified to operate at elevated pressure. The pressure in the Shell gasifier is 3 MPa and it operates at about 2000°C. In the Shell gasifier, the pressure shell is protected from the high reactor temperatures by an internal tube wall (used to raise 5 MPa steam) which in turn, is protected by a thin refractory lining. The ash is recovered mainly as slag removed through a bottom tap, while some also is retrieved from the produced gas by cyclone.

In the Shell gasifier, pulverized coal (<0.1 mm) is carried into the reactor by a transport gas through nozzles entering at opposed ends of the cylindrical reactor. At the nozzle exit, the coal is mixed with oxygen which is the main gasifying agent. Small quantities of steam are added to moderate the temperature in the gasifier. In the experimental plants operated to date, nitrogen has been used as transport gas (and as pressuring gas in the lock-hopper feed system), but cooled, clean product gas would be used in a commercial plant. The impinging jets of coal and oxygen create a high temperature reaction zone in the reactor. Slagged ash particles either fall and are trapped through a bottom slag hole, or are carried overhead with the product gas. The product gas is quenched with recycle product gas at the top of the reactor to solidify any molten slag particles before passing into the waste heat recovery boiler.

The Shell gasifier concept was developed in a 6 t/d pilot plant at the Shell Research Laboratory in Amsterdam and has also been operated in a 150 t/d prototype plant at the

Deutsche Shell Refinery at Harburg, near Hamburg, West Germany. The 150 t/d unit will produce about 13,000 m³/d of product gas. Shell projects that the next development stage will involve 1,000 t/d units and that a commercial scale unit would be capable of processing 2,500 t/d of coal to yield about 200,000 m³/hr product gas.

Because of the high temperature of the gasification process, product gas contains even less CO₂ than the Texaco unit, down to about 1.5% and is composed mainly (97%) of CO and H₂.

This gasifier is not yet being marketed commercially, and is still under development. Process modifications being considered include recycle of cycloned ash to try to recover all ash as slag, eliminating water cooling by improved refractory lining and development of a water quench when the product gas must subsequently be shifted.

References: Kraayveld (1978)
Van Oorsouw (1979)
Vogt (1981)

Saarberg-Otto Gasifier

The Saarberg-Otto gasifier Figure E-4 was developed from an earlier slag bath gasifier, and depends on the molten slag to protect the reactor shell. The process is being tested in a demonstration unit which has a diameter of 1.4 meters (I.D.) and is about 17 meters high. This gasifier operates at a pressure of 2.5 MPa with gasification temperatures of about 2000°C. The demonstration gasifier, at Völklingen/Fürstenhausen, will process 264 t/d of coal to yield 22,800 m³/hr of product gas.

In the Saarberg-Otto gasification process, the pulverized coal is introduced into the pressurized system by lock-hopper and then transported by screw feeders to the injection tubes. It is transported through the injection tubes to the nozzles entering the reactor by recycled product gas and is mixed there with the oxygen and steam required for gasification. The nozzles are arranged so that the injected streams enter in a downward, tangential direction and impinge on the slag bath at the lower end of the reactor, causing it to rotate. The rotation of the slag bath improves the heat distribution in the area of impingement while the rotation of the gas stream as it rises to the product gas outlet causes many of the slag particles to impinge on the water cooled wall and flow down to the slag bath. The product gas, prior to exiting from the gasifier, is quenched with recycle product gas to solidify any entrained slag particles.*

* Slag from the slag bath overflows into a slag quench chamber from which it is removed by lock hopper.

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
EVALUATION OF HIGH PRESSURE SAARBERG/OTTO GASIFIER

GASIFIER

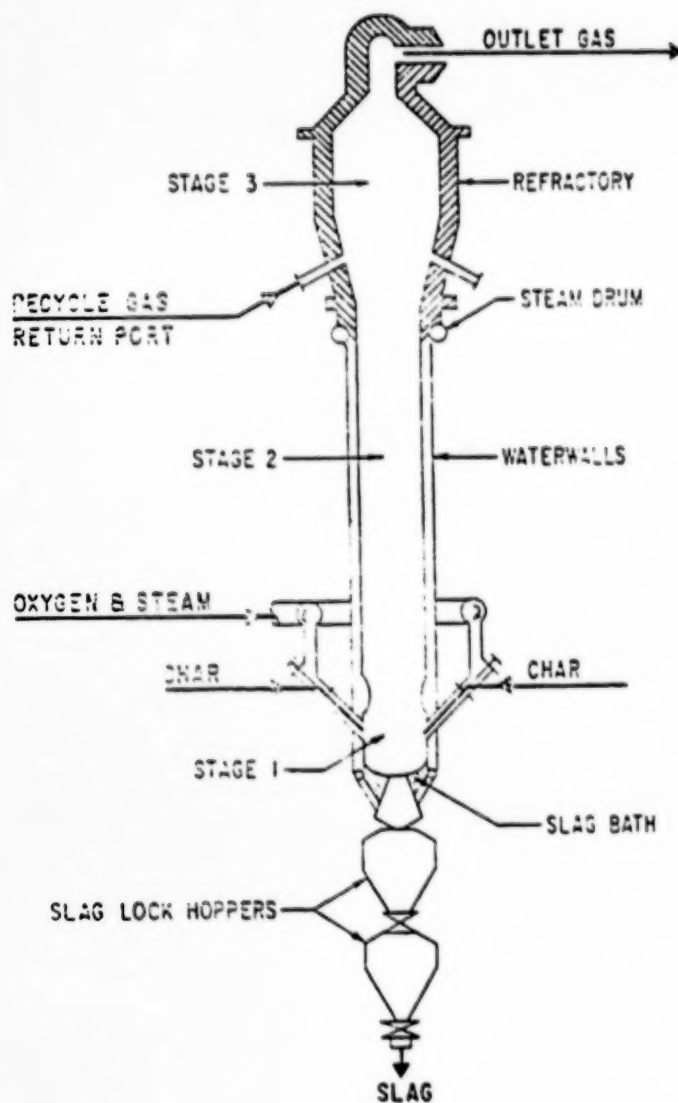


FIGURE E-4

In the demonstration gasifier, the pressure shell is the outside wall, while a tube wall cooled by water and an interior lining of castable refractory are inside. Experience with the system has shown that the castable refractory will be replaced with solidified slag in time.

The estimated commercial scale for the Saarberg-Otto gasifier is 3 meters in diameter which would correspond to a height of about 36 meters. It would be able to process about 1,200 t/d of coal and product approximately 105,000 m³/h of product gas.

References: Fussmann (1978)
Manthos (1977)

Bi-Gas Gasifier

The Bi-Gas gasifier is one of the second generation gasifiers which did not arise out of an existing unit. It was developed starting in 1965, by Bituminous Coal Research, Inc., (BI-GAS) from bench scale to a 120 t/d pilot plant at Homer City, Pennsylvania. The pilot unit is 1.52 meters in diameter (O.D.) and has an overall height of 16.4 meters.

The Bi-Gas process is more complex than the other gasifiers and involves gasification of pulverized coal in a stream of hot combustion gas i.e., in Stage II of Figure E-5 separation of the char produced and its recycle to generate the combustion gas. Steam is injected with the coal for gasification and is also used as the carrier for the transport of char to the char burners. The coal is transported by recycle product gas.

The gasifier is a two-stage unit which operates at 6.9 MPa. The gasification stage operates at about 1050°C while the char burner operates at 1600°C. Both are refractory lined, and have cooling coils embedded in the refractory and inside the pressure shell. Slag is separated in a water quench (unlined) below these two stages and is removed as a water slurry. The gasifier is shown in Figure F-5.

A commercial size Bi-Gas gasifier is estimated to be approximately 30 meters high and to have first stage and second stage internal diameters of 1.68 meters and 2.10 meters respectively. The commercial unit is expected to process approximately 3800 t/d of coal and to produce about 8.0 Mm³/d of product gas.

Reference: Dravo (1976)

BI-GAS GASIFIER

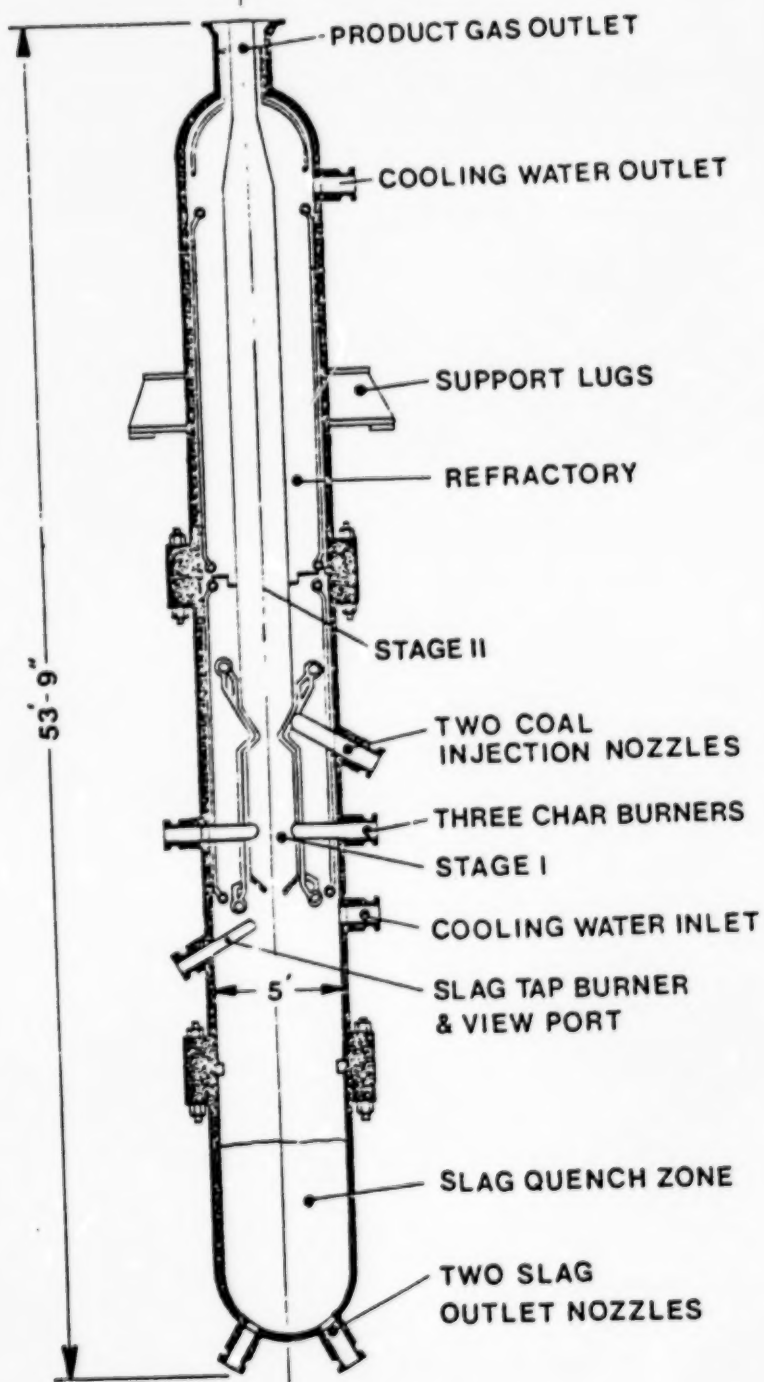


FIGURE E-5

EVALUATION

The anticipated applications of coal gasification in Canada over the next 20 years are likely to be:

1. Synthesis gas manufacture for chemical synthesis.
2. Gas manufacture to increase hydrocarbon recovery from other sources (i.e., H_2 and/or CO_2).
3. Fuel gas manufacture for heavy oil recovery or process heating.
4. Fuel gas manufacture for power generation.

Chemical synthesis can be used to produce transportation fuels, as at Sasolburg and Secunda, South Africa, but is not likely to find this application in Canada within the time frame of this study. Most likely would be the generation of synthesis gas for methanol production or hydrogen for ammonia production, both technologies practiced elsewhere at present, although not using pressurized gasifiers. The move towards pressurized gasification for these applications will be general, however, as increasing compression costs will make it more economical and increased experience with pressurized gasifiers will improve their reliability and operability.

Generation of hydrogen for upgrading and CO_2 for enhanced recovery are also potential applications for coal gasification in Canada, although how they will compare economically with alternative sources requires further study.

Use of coal as a supplemental fuel for heavy oil recovery was considered in the early versions of the Esso Cold Lake

Project although the idea was subsequently dropped. Each potential application must be considered in its own particular terms to see if greater recovery can be realized by the use of imported solid fuel and also whether the fuel gas route is the best route for use of solid fuel. The advantages of the gasification route for using solid fuels are:

1. Sulphur can be removed more readily than from stack gas.
2. Distribution is simpler and cheaper if the requirements for fuel are distributed.
3. Process control is generally simpler and more effective with a gaseous fuel than with a solid fuel.

The use of the fuel gas route for power generation from solid fuel is a route which can become interesting if stack gas cleanup is required or if the cost differential between gas-fired and coal-fired power stations becomes sufficient.

Considering the gasifiers described above for these potential applications within the terms of the study leads to the following considerations:

Fixed or moving bed gasifiers - Neither the Lurgi nor the BGC-Lurgi is suited for synthesis gas production. Both produce substantial methane (CH_4) and would require additional gas processing. For fuel gas production, they operate predictably and can produce a product gas of consistent quality. Gas liquor disposal would be a

significant problem. Their high maintenance requirements would not be conducive to field installations.

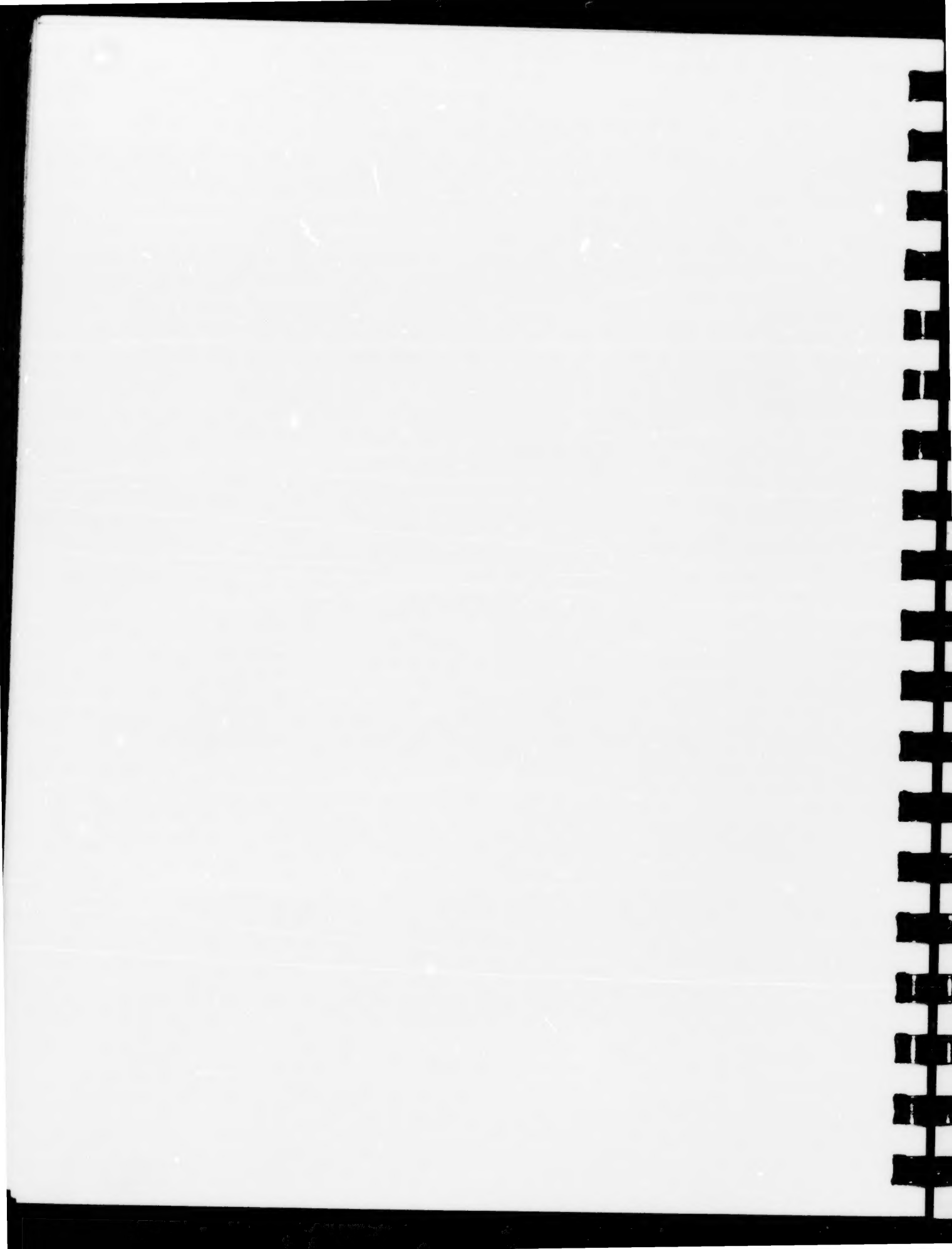
Overall evaluation: Most likely applications would be fuel gas manufacture for process heating or power generation. Unlikely within projected time frame.

Fluidized bed gasifiers - It is not likely that an 0.4 MPa Winkler would be chosen over the 1.0 MPa if both were available. Both suffer from the carryover of unreacted fuel and the residual carbon in the ash discharge. The modifications to recycle char recovered from the produced gas avoids the first problem to some degree. The gas produced does have about 3% methane which would be a disadvantage for synthesis gas use, but might not be too disadvantageous.

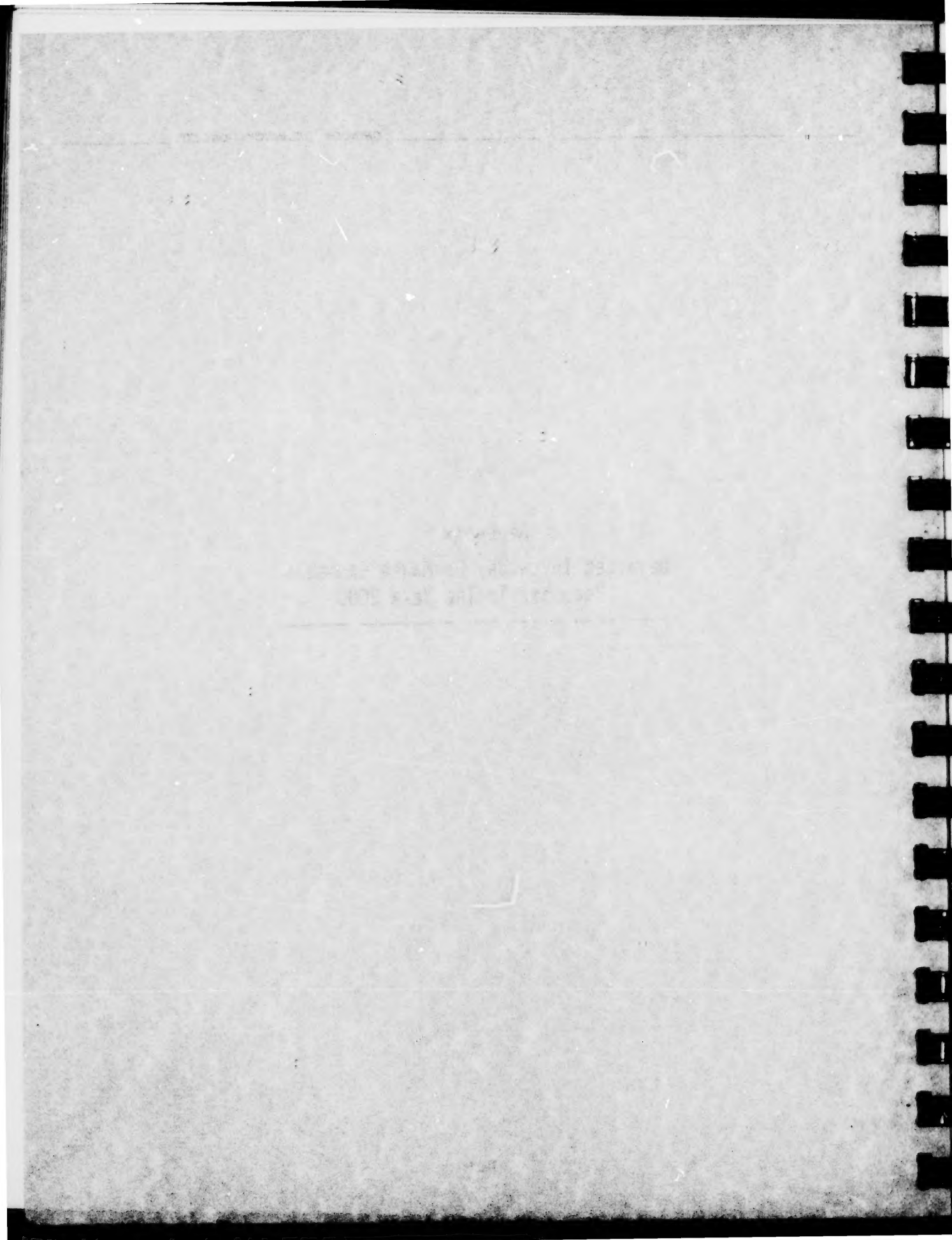
Overall evaluation: Most likely application would be HTW for CO₂ manufacture or fuel gas if char recycle can be developed sufficiently. Unlikely within the project time frame.

Entrained gasifiers - The gas composition from entrained gasification is most suited to synthesis gas applications and ash produced as slag is generally innocuous. The use of entrained gasifiers for gas manufacture and steam generation in connection with heavy oil recovery is an interesting concept which may prove viable. The most likely applications are for synthesis gas production for methanol and ammonia production.

Overall evaluation: The Saarberg-Otto and Bi-Gas processes are still in the development stage and will not likely be available commercially in time to contribute this century. The Texaco and Shell gasifiers are difficult to separate for these applications, but at present, the Texaco probably has an edge because of its longer history. Two or three plants using these gasifiers could be in operation before the year 2000.



APPENDIX F
DETAILED INVENTORY OF MAJOR CANADIAN
PROJECTS TO THE YEAR 2000



This inventory of major Canadian projects to the year 2000 is based on information concerning investment intentions within various sectors obtained during the course of Task Force subcommittee work and through a canvass of Task Force members. It includes only those projects with a cost of \$100 million or more and specifically excludes real estate and property development projects. Because of the wide variation of information sources, the project cost estimates included in the inventory are not stated on a completely consistent basis throughout. It is understood that most of the estimates are escalated to the year of expenditure by taking expected inflation rates into account. In some cases, however, constant 1980 dollars are used. In a few other cases, where projects have been delayed, cost estimates are stated as if the project had commenced as planned at the time the cost estimate was prepared and have not been adjusted to reflect recent schedule changes. Finally, a number of projects were identified without cost estimates, and in those cases order-of-magnitude capital costs have been estimated by the Task Force as indicated by the notation "(c)" following the cost figure.

Table F-1 Province Sector MULTI-PROV./UNDETERMINED Exploration & Development

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Arctic Pilot Project	LNG	Melville Island to Eastern Canada	2 500				1981 - 86	6.3 x 10 ⁶ m ³ /d; includes necessary pipeline, plants, terminals & tankers (assumes Canso (arctic) repatriation plan)

Table F-2 Province Sector Multi Prov./Undetermined Pipelines

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
AMOCO	Products Pipeline	Nova Scotia/Quebec	140				1982 - 83	
Dome Petroleum	Cushin Pipeline Looping	Alberta and Saskatchewan	125				1982	
Fourkites Pipe Lines	Alaska Gas Pipeline	Alaska/Yukon Border to Southern Canada/US Border	8 365	4 555	11 875	400	1980 - 85	2035 km; 56 x 10 ⁶ m ³ /d
Interprovincial Pipe Line	Norman Wells Oil Pipeline	Norman Wells, NWT to Zama Lake, Alta	365	400-600			1981 - 83	870 km; 324-mm O.D. pipe
Polar Gas	Gas Pipeline	Melville Island to Longlac, Ont.	12 300		36 950	725	1989 - 94	4800+ km; 38 x 10 ⁶ m ³ /d
TQ & M Pipeline	Gas Pipeline and Gas Dist.	Montreal to Quebec and Maritimes	2 285				1981 - 84	Includes Maritime sections and major distribution laterals
TransCanada Pipelines	Bypass Gas Line Looping & Compression	North Bay to Montreal Saskatchewan, Manitoba and Ontario	200				1982/83 - 84	460 km; boucles de 1067 mm d.c.
			560				1980 - 81	11 stations de compression
Transmountain Pipe Line	New Oil Pipeline	Pont Angeles to Edmonton	750				1981 - 83	1125 km; 762-mm O.D. pipe
Unknown	Municipal Gas Dist. Systems	Quebec and Maritimes	1 200+				1981 - 2000	Associated with TQ & M gas pipeline
Unknown	Coal Slurry Pipeline	Hinton Region of Alberta to Pacific Coast	1 000				1983 - 85	Thermal coal

Table F-3 Province Sector Multi-Prov./Undetermined Electric Generation & Transmission

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Unknown	Western Power Grid	Alberta, Saskatchewan and Manitoba	620				- 87	

Table F-4 Province Multi-Prov./Undetermined
Sector Manufacturing

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Dome Petroleum	4 LNG Tankers (122,000 m ³ capacity)		1 400				- 85	To transport output from B.C. LNG Plant
Petro-Canada	Semi-sub. Drilling Rig		100					
Unknown	Class 10 Tankers and Barges		4 320 2 255					To transport oil from Beaufort Sea
Various	Trawler Replacement Program Program - East Coast Fishing Industry		500				1981 - 86 +	Fleet upgrading

Table F-5 Province Multi-Prov./Undetermined
Sector Defence

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Department of National Defence	Fighter Aircraft Patrol Frigates		2 860 1 965				1979 - 87 1979 - 89	

Table F-6 Province ATLANTIC CANADA - NEW BRUNSWICK, NEWFOUNDLAND, NOVA SCOTIA, PRINCE EDWARD ISLAND
Sector Exploration & Development

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Esso Resources	Offshore Exploration	Offshore Nfld.	250				1980 - 85	
Mobil et al	Hibernia Development Sable Island Development	Grand Banks, Nfld. Sable Island, N.S.	8 000 1 000				1983 - 92 1980 - 85	
Labrador Group (Petro-Canada)	Exploration Program	Offshore Labrador	500-1000				1980 - 90	
Shell/Tenaco	Gander Black Exploration	400 km N.E. of St. John's, Nfld.	1 500				1981 - 85	Includes processing and gathering facilities

Table F-7 Province Atlantic
Sector Pipelines

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Mobil et al	Atlantic Gas Pipeline	Sable Island to Mainland N.S.	935				1983 - 84	
Unknown	Oil Pipeline	From Grand Banks Region to Nfld.	250(c)					

**Table F-8 Province Atlantic
Sector Processing & Petrochemicals**

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Petro-Canada	Refinery Reactivation	Come By Chance, Nfld.	200				1980 - 81	
Unknown	Ammonia Plant	Nfld.	200				1981 - 82	
Unknown	Methanol Plant	Nfld.	100				1981 - 82	

**Table F-9 Province Atlantic
Sector Electric Generation & Transmission**

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Nfld & Labrador Hydro	Gull Island-Hydro	Labrador	4 500		11 000	80	1979 - 95	Churchill River; 1700 MW
	Lower Churchill Phase I						1979 - 86	\$1600 million; 600 MW
	Lower Churchill Phase II						1990 - 95	\$2000 million; 1100 MW
	Submarine Power & Cable							2000 approx; 400 kV DC
	Muskrat Falls-Hydro	Labrador	5 200				1981 - 86	600 MW
N S Power	Upper Salmon-Hydro		155				1979 - 82	84 MW
	Hydropower Thermal		100				1981 - 84	
	Transmission/switching		295				1980 - 90	
	Tidal Power Pilot*	Antigonish Basin, N.S.	45			50	1980 - 83	1100 MW (Antigonish Basin)
	Tidal Power Full Scale	Bay of Fundy, N.S.	10 000		8 400		1983 - 95	660 MW
	Conversions Oil to Coal	Various locations in N.S.	2 000				1986 - 91	660 MW
	Nuclear 1		1 020				1980 - 95	2 @ 150 MW
	Nuclear 2		805				1982 - 86	600 MW
	Lingan 3 & 4-Thermal		600				1988 - 92	600 MW
	Unit 2 - Canlub	Punt Lepreau, N.B.	1 790		4 500	227	1989 - 93	600 MW
New Brunswick Power	Unit 1	Punt Lepreau, N.B.	1 160				1983 - 85	60 MW to 320 MW facility
	Grand Lake 9 - Thermal	Newcastle Creek, N.B.	510				1982 - 86	640 MW
	Grand Falls Redevelop-Hydro		900					
Unknown	Nuclear Station		3 510				1981 - 83	150 MW
	Cataract	Unknown	250					

*Included on the basis of new technology

Table F-10 Province Atlantic
Sector Forest Products

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	CONST. MANPOWER MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Canada Int'l Paper N.S. Forest Ind.	Expansion	Dalhousie, N.B.	160					
	Sulphite & Kraft Paper Conversion	Point Tupper, N.S.	150					

Table F-11 Province Atlantic
Sector Mining

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	CONST. MANPOWER MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Kitts/Michelin Devco Potash Corp. of America Devonian Mines	Uranium Mine & Mill	Labrador (Makkovik area)	160					
	Cape Breton, N.S.		400					
	Rehabilitation #26 Colliery	Sydney, N.S.	165		1 500	1 000	1979 - 86 1979 - 84	655 kt/yr.
	Potash Mine & Refinery	Sussex, N.B.	135				- 1982	1.2 - 1.4 Mt/yr.
	Potash Mine & Refinery	Salt Springs, N.B.	150				- 1983	

Table F-12 Province Atlantic
Sector Primary Metals Production

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	CONST. MANPOWER MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Sydney Steel Unknown	Modernization Phase I Phase II	Sydney, N.S. Sydney, N.S.	350 175					
	Aluminum Smelter	Corner Brook or Goose Bay, Nfld.	500				1982 - 90	180 kt/yr. ingot

Table F-13 Province Atlantic
Sector Transportation

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	CONST. MANPOWER MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
National Harbours Board Unknown	Container Port Expansion	Halifax, N.S.	115					
	Port Expansion	St. John's, N.B.	165				1979 - 97 1981 - 91	
	Rail Terminal/ Industrial Park	Halifax, N.S.	120				1983 - 90	

Table F-14 Province Atlantic
Sector Manufacturing

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Michelin	Tire Plant	Waterville, N.S.	400				1980 - 82	

Table F-15 Province Atlantic
Sector Defence

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Department of National Defence	Halifax Base	Halifax, N.S.	280				1979 - 89	

Table F-16 Province QUEBEC
Sector Processing & Petrochemicals

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
CIL	Chloralkali Plant		100				1979 - 82	
Gulf Canada	Refinery - Modernization and Upgrading	Montreal	100				1981 - 83	
Gulf Canada et al	Heavy Fuel Oil Upgrader	Montreal	1 500				1982 - 85	7.9 - 9.5 x 10 ⁹ m ³ /d
Petroleum Inc. (Gulf/Union Carbide/Gov't of Quebec)	Olefins Plant - Expansion	Varenes	500			350	1981 - 85	Approx. 180 kt/yr. ethylene
Ultramar - Golden Eagle Refinery	Cut Cracker for Resid. Oil	Quebec City	150				1980 - 82	Fluor - general contractor
Unknown	Vinyl Chloride Monomer		100				1988 - '90	
Unknown	Titanium Oxide		150				1985 - 86	
Various	Downstream Derivatives, Varenes Expansion		500				1983 - 87	

Table F-17 Province Quebec
Sector Electric Generation & Transmission

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER		OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
				PEAK FORCE	MAN YEARS			
Hydro Quebec	La Grande River Phase I	James Bay	1 565				1980 - 86	3000 MW
	La Grande River Phase II	James Bay	7 290				1985 - 92	
	Notaway Brook & Rupert-Hydro - Phase I	James Bay	10 240				1981 - 90	8500 MW
	Grande Baleine	James Bay	20 000				1980 - 2000	
	DeLany-Pump Storage	James Bay	7 600				1981 - 90	1500 MW
	Aschumabuchan Substation	Saguenay/Lac St. Jean Area	1 000				1983 - 87	
	Laprade Heavy Water Plant		1 000				1989 - 95	
	MANIC - 5 Manicouagan Project		900		7 500			Capacity expansion
	Gentilly No. 2 - Nuclear	Gentilly	400				1980 - 85	685 MW
	Gentilly No. 3 - Nuclear	Gentilly	2 895				1985 - 95	850 MW
	Gas Turbines	Various	1 705					Peaking units
	Hydro - others	Various	1 565				1986 - 90 +	
	Nuclear - others	Various	1 125				1985 - 90 +	
	High Voltage Transmission	James Bay	1 750				1981 - 90	255 kV
	High Voltage Transmission	Various	5 470				1981 - 90	Up to 315 kV

Table F-18 Province Quebec
Sector Forest Products

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER		OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
				PEAK FORCE	MAN YEARS			
Consolidated Bathurst	Modernize & Expand	Trois Rivières Shawinigan Grande Merle	155				1980 - 82	
Domtar	Modernize & Expand	Lebel sur Quevillon Dunrobin Amos	135				1981/82-1986/87	145 kt/yr.
Donaluc Normik & Inc.	Newsprint Mill	Amos	190				1980 - 82	450 t/d
Rexford/Soucy	Newsprint	Various	230			430	1981 - 90	Pulp and paper
Various	Modernize & Expand	Various	500 +					

Table F-19 Province Quebec
Sector Primary Metals Production

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER		OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
				PEAK FORCE	MAN YEARS			
Alcan	Aluminum Smelter	Grande Bale	500				1980 - 82	170 kt
Canadian Reynolds Aluminum	Aluminum Smelter Expansion - Phase II	Baie Comeau	100				1980 -	
Unknown	Pure and Aluminum Smelter	Saguenay Region	700				1981 - 86	Pure - \$100 million, Smelter - \$100 million

Table F-20 Province Quebec
Sector Transportation

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Gov't of Canada Ministry of Transport National Harbours Board Montreal Urban Community City of Quebec Gov't of Quebec/Gov't of Canada	Gros Cacouna Port	Gros Cacouna	315				1981 - 95	
	Mirabel Phase II		300				1983 - 88	
	Bulk Harbour Facilities	Montreal	300				1981 - 85	
	Subway Line 5	Montreal	100				1982 -	
	LRT	Quebec	300(c)					
	Montreal Area Integrated Transport	Montreal Region	1 000				1980 - 85	Expand CN/CP commuter, subway (subway \$480 million + \$400 million; highways \$120 million)

Table F-21 Province Quebec
Sector Manufacturing

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Deutz Diesel	Diesel Engine Plant	Montreal	175					

Table F-22 Province ONTARIO
Sector Processing & Petrochemicals

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Esso Chemical Mobil Petrostar/Suncor Polyar Unknown	Low Density Polyethylene	Sarnia	100				1981 - 83	135 kt/yr.
	Polypropylene		100				1984 - 87	
	Residual Oil Upgrading	Sarnia	500				1983 - 85/86	72 x 10 ³ m ³ /d (2 separate projects?)
	Isobutylene/Buyl Rubber Expansion	Sarnia	180				- 82	
	Gas Cracker Expansion		105				1981 - 83	

Table F-23 Province Ontario
Sector Electric Generation & Transmission

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Gov't of Ontario Great Lakes Power Inco Ontario Hydro	Waste Energy Projects (Biomass)	Various	3 200				1990 - 95	
	Power Gen. - Hydro	Sault Ste. Marie	100				1979 - 82	45 MW
	Power Dam & Dist. - Hydro	St. Mary's River	170				1980 - 85	
	Mission Isl. Gen. Sta. - Thermal	Thunder Bay	410				1979 - 82	2 units; 100 MW
	Aitken - Thermal	Marmion Lake	800				1979 - 88	400 MW
	Pickering B. Nuclear		2 210	700	9 135	450	1979 - 85	4 units; 2000 MW
	Lincoln B. Nuclear		5 400		12 000	600	1979 - 87	4 units; 3000 MW
	Darlington - Nuclear	Port Elgin	3 300		14 610	600	1979 - 91	4 units; 3000 MW
	Nuclear	Brownsville	6 000				1985 - 90	1 unit; 3000 MW
	Hydro		3 700				1987 - 90	7 units; 100-100 MW
	Transformer Station/Lines		11 815				1979 - 99	
	Lignite Thermal	Onkewana (240 km north of Timmins)	1 000				1986 - 92	Open pit mine & power

Table F-24 Province Ontario
Sector Forest Products

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Abitibi Price Domtar E.B. Eddy Great Lakes Forest Products Ontario Paper	Pulp & Paper Modernization	Thunder Bay	700				1979 - 84	
	Modernize & Expand	Cornwall	120					
	Modernize & Expand	Espanola	250				1980 - 83	
	Modernize & Expand Pulp Mill	Dryden	335				1980 - 88	
	Modernization	Thornhill	260				1980 - 83	

Table F-25 Province
Sector Mining

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
AECL	Plutonium Extraction Plant	Lake St. Joseph Area	1 500	1 600		725	1983 - 85	
Algonia	Iron Ore Development	Elliot Lake	1 200				1988 - 99	3.6 Mt/yr. gross pellets (first phase = \$520 million)
Denson Mines	Expand Mine & Mill (Uranium)	Blind River	200				1978 - 85	Expansion to 10.5 kt/d ore
Elkorado Nuclear	Uranium Refinery	Sudbury	190				1979 - 81	
Falconbridge	Fraser Nickel/Copper Mine	Elliot Lake	125			1 000	1979 - 81	
Preston Mines Ltd.	Reliab. Stanleigh Uranium Mine & Mill	Elliot Lake	200(c)					4.5 kt/d ore
Rio Algom Mines	Expansions & Rehabilitation (Uranium)	Elliot Lake	185				1978 - 84	
Texas Gulf	New Copper Smelter	Kid Creek	300				1979 - 81	

Table F-26 Province
Sector Mining

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Algonia Steel	Seamless Tube Plant Exp. Finishing Facilities	Sault Ste. Marie	100	500		500	1979 - 84	180 kt/yr. 90 kt/yr.
Atlas Steel	Steel Plant Expansion	Welland	200				1981 - 84	
Indecon	Hot Strip Mill	Hamilton	100				1980 - 83	1.1 Mt/yr.
Stelco	Steel Mill Expansion	Nanticoke	450				1979 - 84	
			360					

Table F-27 Province
Sector Manufacturing

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Canadian	Challenger Extension	Windsor	100(c)				1980 - 85	
Chrysler	Plant Conversion & Expansion	Toronto	1 000			3 000	1981 - 85	
De Havilland	Dash 8 Plant Facilities	Windsor	150			3 100	1979 - 81	6.18 000 units/yr
Ford	Engine Plant - V6	Windsor	500					
General Motors Ltd.	Automatic Transmission Plant	Windsor	1 000(c)					
	Engine Plant	St. Catharines	1 000(c)					
	Plant Conversion - Axles to Transmissions	St. Catharines	250				1980 - 82	

Table F-28 Province
Sector Transportation

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
National Capital Region (NTC)	LRT	Ottawa/Hull	500(c)				1981 - 90	
Toronto Transit	Scarborough Line	Toronto	150					

Table F-29 Province
Sector Electric Generation & Transmission

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Manitoba Hydro	Waskesia Hydro	Thompson River	540				1970 - '88	280 MW
	Conawapa G.S. Hydro	Lower Nelson	2 695				1975 - 2002	1120 MW
	Manitoulin G.S. Hydro	River	1 540				1987 - '93	1100 MW
	First Rapids Hydro		500				1970 - '88	117 MW
	First Rapids Hydro		500				1975 - 2000	210 MW
	HWDC Conversion-Trans.		440				1981 - 89	
	Burnt River Transmission		345				1980 - 2000	
	Complex		235				1985 - 95	500 kV
	Winnipeg/Brandon-Trans.		3 185				1979 - 97	
	Domestic Budget Dist. & Transmission		305				1990 - 97	

Table F-30 Province
Sector Mining

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
International Minerals and Chemical Corp.	Powder Mine	St. Lazare	500			400 +		1.8 Mt/yr.

Table F-31 Province
Sector Primary Metals Production

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Alcan	Aluminum Smelter		500			700 +		

Table F-32 Province
Sector SASKATCHEWAN Heavy Oil Development

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Imperial	Enhanced Oil Recovery	Hardisty	1 750			200	1980 - 2000	Includes work in Alberta

Table F-33 Province Saskatchewan
Sector Processing & Petrochemicals

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Husky et al Ockla/Potash Corp.	Heavy Oil Upgrading Ammonia and Fertilizer	Lloydminster	1 000 300		3 500	200	1981 - 86	Minimum capacity of 4.8 x 10 ⁶ m ³ /d

Table F-34 Province Saskatchewan
Sector Electric Generation & Transmission

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Sask Power Corp.	Poplar R. #2 - Thermal Nipawin - Hydro Steam #1 - Hydro Steam #2 - Hydro Thermal Station Winnipeg - Hydro New Thermal #1 Chancellor - Hydro	Canonauh Estevan	170 315 240 270 580 645 465 675				1979 - 83 1982 - 86 1983 - 89 1987 - 91 1989 - 94 1990 - 94 1992 - 96 1993 - 99	280 MW 252 MW 280 MW 280 MW 100 MW 465 MW 252 MW

Table F-35 Province Saskatchewan
Sector Mining

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Anok Ltd. Canadian Occidental Eldorado Nuclear Esso et al KLMC (SMDC et al) Potash Corp. of Saskatchewan	Uranium Mine & Mill Uranium Mine & Mill Uranium Hexafluoride Plant Uranium Mine & Mill Uranium Mine & Mill Mine Expansion Other Expansions - Potash Bredentbury Mine (New)	Cluff Lake McLean Lake Warman Melvest Lake Key Lake Langman Mine Various S.E. of Yorkton	165 1000e 100 100 + 500 440 1 570 680			200-400 500 250	1979 - 81 1983 - 86 1981 - 83 1981 - 83 1979 - 89 1982 - 86	1.5 kt/yr. uranium 3.4 kt/yr. uranium oxide 1.8 kt/month increase Increase capacity 5.6 kt/yr

Table F-36 Province ALBERTA
Sector Exploration & Development

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Esso Resources Canada Ltd Gulf Canada	C.O. Mobile Fluid Gas Processing Plant	Judy Creek - Swan Hills Area Hanlon Area	500 200				1982 - 85 + 1981 - 83	Project recently cancelled by sponsor 6.8 x 10 ⁶ m ³ /d. Parrot Lavalin

Table F-37 Province Alberta
Sector Heavy Oil Development

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Esso Resources Canada Ltd. Gulf Canada Nova/Petro-Canada Shell Canada et al Suncor Synkrude Unknown	Cold Lake In-Situ Oil Sands Sunalta Oil Sands Mining Oil Sands Mining Peace River In-Situ Alabards Project Oil Sands Plant Exp. Plant Exp. - 3rd Train. Combustion Pilot Plant	Cold Lake Fort McMurray Region Fort McMurray Peace River Fort McMurray Fort McMurray Fort McMurray Cold Lake	7 000 10 000 10 000 5 000 7 200 185 1 500 100	6 885 3 000 8 185 750 1 500	23 040 17 090 900 8 000	2 400 2 000 + 3 200 + 175 1 000	1981 - 89 1986 - 90 1985 - 90 1985 - 92 1980 - 87 - 81 1984 - 86 1985 - 87	22 x 10 ⁶ m ³ /d. 1000 ft and 1500 ft SSR 1 W/Lavalin 21-22 x 10 ⁶ m ³ /d 22 x 10 ⁶ m ³ /d. includes new town 2.1 x 10 ⁶ m ³ /d. 1000 ft and 1500 ft 9.5 x 10 ⁶ m ³ /d. mining & upgrading

Table F-38 Province Alberta
Sector Processing & Petrochemicals

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Alberta Energy Co. Alberta Energy/DuPont Alberta Energy/Esso Alberta Energy/Esso Chemical (Pecalta) Alberta Gas Chemicals Alberta Gas Ethylene AOSTRA Canadian Fertilizer Celanese Canada Inc. Clt. Inc. City of Medicine Hat Dow Chemical Esso Chemical Canada Gulf Canada	Synthetic Nat. Gas Plant Linear Polyethylene Plant Benzene Plant Ethylbenzene/Styrene Plant Methanol Plant Expansion Ethylene II Ethylene III Synth. Oil Upgrading Plant Ammonia/Urea Plants Methanol Plant Polyethylene Plant Expansions Coal Gasification Pilot Plant Vinyl Chloride Monomer Ethylene Glycol Ammonia/Urea Fert. Plant and Plant Expansion Refinery Expansion	Bruderheim Edmonton Area 13 km N.E. of Fort Sask. Bruderheim Medicine Hat Joffe Joffe Edmonton Edmonton Medicine Hat Region Fort Sask. Fort Sask. Redwater Edmonton	140 200 225 300 140 375 590 200 200 255 165 200 + 165 100 345 100	600 900 400 950 1 040 200 255 165 200 255 165 200 + 165 100 345 100		60 200 120 100 80 90 1 800	- 82 1981 - 84 1981 - 84 1981 - 84 1979 - 82 1981 - 83 1983 - 85 1980 - 83 - 82 1980 - 84 1990s 1979 - 81 1980 - 84 1980 - 82 1980 - 83	1.6 x 10 ⁶ m ³ /yr. SNG 227 kt/yr. 500 kt/yr. 400 kt/yr. Expansion to 2.4 kt/d 551 kt/yr. 600 kt/yr. 2.1 kt/d. EPC contractor - IPIs Increase capacity from 35 kt/yr. to 175 kt/yr. in two phases Feasibility study - Fluor Canada Expansion to 660 kt/yr. new production of 1.6 kt/yr. ammonia and 1.5 kt/yr. urea Increase capacity by 6.4 x 10 ⁶ m ³ /d to 19.2 x 10 ⁶ m ³ /d

Table F-38 Province Alberta
(Cont.) Sector Processing & Petrochemicals

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Imperial Oil	Refinery Expansion	Edmonton	185				1981 - 84	Increase capacity by 7 x 10 ⁶ m ³ /d to 12 x 10 ⁶ m ³ /d
Nova/Shell	Styrene Plant	Scarford	160	410	600	120	- 84	900 kt/yr.
	Linear Low Density Polyethylene Plant	Joffre	250		600	75	- 84	270 kt/yr.
Petro-Canada	Heavy Oil Upgrading	Hardisty	800		5 000	300	1983 - 86	16 x 10 ⁶ m ³ /d
Shell	Benzene Refinery	Fort Sask.	195			200	1981 - 84	Diesel & hydrocarbon byproducts
Shell/Husky	Synthetic Oil Refinery	Fort Sask.	420	2 000		200	1980 - 84	8 x 10 ⁶ m ³ /d
Shermont Gordon	Nitrogen Fert. Plant	Fort Sask.	265				1980 - 83	
Turbco Resources	Refinery	Balzac	140				1980 - 82	4 R x 10 ⁶ m ³ /d; under const.
Union Carbide	Ethylene Glycol Plant	Premiss	300				1981 - 84	225 kt/yr.
Various with Fed./Prov. Gov't	Coal Gasification/Liquefaction Coal Petrochemicals		1 800 2 000		8 000	800	1988 - 94 1988 - 96	
Various	Styrene Derivatives		2 000					

Table F-39 Province Alberta
Sector Electric Generation & Transmission

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Alberta Power	Battle River #5-Thermal Sherwood-Thermal	Foreburg Hanna	240 740			530	1979 - 82 1981 - 86	
Calgary Power	Sundance #6-Thermal Keppells-Thermal Keppells Exp.-Thermal Canmore Ryley-Thermal	Parkland	200 615 865 4 600				1979 - 81 1979 - 84 1983 - 87	750 MW; mine exp. to 10.9 Mt/yr. 750 MW 2250 MW
Edmonton Power	Genesee-Thermal	65 km S.W. of Edmonton	1 505	800		240	1987 - 97	4 x 375 MW 2000 MW; for power export to U.S.
Fording Coal	Thermal Power Plant		4 500					3 x 375 MW 1500 MW
General (ownership not yet determined)	Thermal Units Dunvegan-Hydro Mountain Rapids-Hydro Gen & Trans. Gas Fuel Turbine Peaking Contingent Project	Peace River Slave River	2 140 1 815 2 000(e) 170 580				1979 - 98 1983 - 93 1996 1995 - 99	1500 MW; 1000 km DC transmission

Table F-40 Province Alberta
Sector Forest Products

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
B.C. Forest Products	Sawmill Pulp & Paper Mill	Fox Creek Granite Cache	500 900			760	1981 - 85 1980 - 85	

Table F-41 Province Alberta
Sector Mining

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Cardinal River Coals	Hydraulic Coal Mine	South of Hinton	200(e)					2 Mt/yr.
Consolidation Coal	Open Pit Coal Mine	Nordeg	150					2.5 Mt/yr.
Esso Resources	Open Pit Coal Mine	Judy Creek	345	175		140	1982 - 84	
Fording Coal	Open Pit Coal Mine	Red Deer (Shaughnessy)	150(e)					1 Mt/yr.
Fording/Petro-Canada	Thermal Coal Mine	Lethbridge	100			350-400	1982 - 83 1982 - 83	1.6 Mt/yr. 200-300 kt/yr.
Grege River Resources	Open Pit Met. Coal	Coal Branch	185					900 kt/yr.
Luxar	Thermal Mine Exp.	Coal Valley	250(e)					
McIntyre Mines	Met. Coal Mine	Near Grande Cache	100(e)					
Petro-Canada	Kipp Underground Coal Mine	Near Lethbridge	200(e)					
Petrofina	Thermal Coal Mine	Near Shaughnessy	150(e)					
Shell	Gleichen Mine	Gleichen	200(e)			500	- 84	
Union Oil/Recon	Open Pit Coal Mine	Obed	400	200-500		540	1981 - 83	4 Mt/yr. 500 kt/yr.
Unknown	Underground Coal Mine	Sam River	400(e)					500 kt/yr.
Unknown	Underground Coal Mine	Grassy Mountain	400(e)					

Table F-42 Province Alberta
Sector Transportation

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
City of Edmonton	LRT - South East Leg	Edmonton	575				1980 - 84	
City of Calgary	LRT - MacLeod Trail LRT - Northwest Leg	Calgary Calgary	180 100				1980 - 82 1982 -	
Gov't of Alberta	High Speed Rail Link	Calgary-Edmonton	200					
Northern Alberta Railway	Railway Extension	Fort McMurray North	100					

Table F-43 Province Alberta
Sector Manufacturing

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Canada Cement	Cement Plant Expansion	Edmonton	150					

Table F-44 Province BRITISH COLUMBIA
Sector Exploration & Development

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Petro-Canada	Sour Gas Plant	Fort St. John	250					

Table F-45 Province British Columbia
Sector Pipelines

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
B.C. Hydro	Gas Pipeline to Vancouver Island and Gas Dist.	From Mainland South of Vancouver to Vancouver Island	230					Direct costs only; 1980 dollars
Transmountain Pipe	Coal Slurry Pipeline		200					
Westcoast Transmission	Gas Transmission Sulphur Scrubbing Plant Pipeline Looping	Williams Lake to Comox Dawson Creek	185 125 150					

Table F-46 Province British Columbia
Sector Processing & Petrochemicals

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
B.C. Hydro	Coal Liquefaction	Hat Creek	5 000	20 000		2500-5500	1983 - 90	7.9 x 10 ⁶ m ³ /d
Dome Petroleum	LNG Plant		1 400				- 85	2.6 Mt/yr.
Dome/Westcoast/CanOxy/Mitsubishi	Ethylene and Two Derivative Plants	Fort St. John Region and Coast	2 000		7 700	1 200	- 85	2.7 Mt/yr. ethylene production
Chelex Industries Ltd	Methanol Plant	Kittimat	140				1980 - 81	1.2 kt/d.
Westcoast Transmission	Methanol Plant	Kittimat	175				1981 - 82	
Westcoast/Petrocan/Mitsui	LNG Plant	Kittimat	1 500				1982 - 85	
Unknown	Anomina Plant	Northeast B.C.	200				1981 - 82	

Table F-47 Province British Columbia
Sector Electric Generation & Transmission

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
B.C. Hydro	Thermal Plant Revelstoke-Hydro Site C Pea.-River Hydro Ashcroft Fluidized Bed Coal Demo Plant Geothermal Pilot Plant Sikine Island Dev.-Hydro Land Hydro Gen. & Trans. MacGilligan Diversion-Hydro East Kootenay Thermal West Kootenay Dam-Hydro Murphy Creek-Hydro	Hat Creek Fort St. John	3 340 1 200 1 095 145 85 5 505 10 905 100 1 500 250 665 1 985	3 500 2 800	5 000 11 000 800	300 80 200	1985 - 94 1979 - 85 1979 - 89 1990 1990 1988 - 99 1990 - 99 1981 - 86 1990 - 95 1990 - 95 1990 - 95 1980 - 89 1979 - 85 1979 - 84 1979 - 85 1979 - 82 1979 - 82 1980 - 86	2000 MW 6 x 450 MW 975 MW 70 MW 1500 MW 2 lines, 500 kV 500 kV 6 x 450 MW 4 x 175 MW 4 x 175 MW 2 x 450 MW; 2610 MW plant total

*Included on the basis of new technology.

Table F-48 Province British Columbia
Sector Forest Products

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
B.C. Forest Products	Thermomechanical Pulp Mill and Sawmill	Hammond (Crofton)	185				1980 - 82	
Canadian Cellulose	Expand Bleached Kraft Mill	Canlegar	250-360				1981 - 84	
Crown Zellerbach	Expand Newsprint and Modernizations	Elk Falls	250	600			1979 - 81	
MacMillan Bloedel	5 Yr. Expansion Plywood Mill/Inner Board Plant Pulp & Paper Exp.	Port Alberni Port Alberni	1 500 220 165				1979 - 84	Or alternative project
Northern Pulp	Kraft Pulp Mill	Prince George	300	350-1000			1980 - 82	
Rapraer Canada	Wood Fibre Kraft Pulp	Squamish	400				1980 - 85	

Table F-49 Province British Columbia
Sector Mining

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Amstar	Climax Moly Mine	Kitsault	160			1979 - 82	
BP	Coal Mine	Sukunka - Northeast B.C.	400 +			- 85	
Cominco	Equipment Modernization Expansion	Kimberley/Trial	400	400		1980 - 89	Approx. 135 design staff
	Mechanize Sullivan Mine	Kimberley	500			1982 - 87	3.6 Mt/yr.
	Quintette Coal		400			1983 - 84	3.6 Mt/yr.
	Open Pit Coal	Elk River	500			1985 - 88	3.6 Mt/yr.
Elco Mining	Molybdenum Mine	Trout Lake	200				
Esso	Copper/Zinc Mine	Kutcho Creek	180				
	Expand Elkford Coal		150				
Fruding	Molybdenum	Highland Valley	125			1980 - 83	
Highmount Mining	Sparwood Coal	Southeast B.C.	200			1980 - 81	
Kaiser	Expand Copper/Moly.	Highland Valley	160			1985 - 89	2.7 Mt/yr.
Laroc	Munkman Pass Coal		500			1979 - 81	
Petro-Canada	Houston Mine	Near Prince George	105				
Placer/Equity Silver	Sage Creek Coal		400		1 500	1979 - 82	2.7 Mt/yr.
Rao Algom	Line Creek Coal	Near Fernie	180			1979 - 83	7.6 Mt/yr.
Shell	Highmount Copper/Moly	Near Kamloops	150	850		- 80	23 kt/d
Teck Corp	Bollnhouse Coal Field	Cherwood	140			1979 - 83	1.4 Mt/yr.
Valley Copper		Highland Valley	400-500			1981 - 83	Approx. 100 kt/d copper, molybdenum & silver (125 kt/yr copper; 3.3 kt/yr moly; 48 x 10 ⁶ g/yr silver)

Table F-50 Province British Columbia
Sector Primary Metals Production

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Alcan	Aluminum Smelter Exp and Power Plant	Kernano	2 000			1980 - 95	

Table F-51 Province British Columbia
Sector Transportation

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
B.C. Dept. of Highways	Coquihalla Hwy	To Merritt	250			1979 - 85	
B.C. Railway	Nord. East Coal Rail Exp.	N.E. B.C.	485				
City of Vancouver	LRT Project	Vancouver	320			1982 - 84	Coal terminal \$70 million and grain terminal \$200 million
Gov't of Canada/Alberta Wheat Pool	Port/Terminal - Ridley Island	Prince Rupert	270			1980 - 82	
National Harbours Board	Roberts Bank Terminal	Vancouver	100				
CNR	Rail Upgrading & Unit Trains (Coal)		160			1983 - 89	16 km
CPR	Beaver Cuts/Tunnel Tunnel Grade Improvements, etc	Mainline - Roger's Pass Area Various	100 200				

Table F-52 Province Yukon/NWT
Sector Exploration & Development

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Dome Canmar	Oil Development-Offshore	Beaufort Sea	25 000			1982 - 92	Exploration & development
Dome	Beaufort Sea Gas	Beaufort Sea	23 000			1982 - 90	
Esso Resources	Beaufort Sea Expl. & Dev. Taglu Gas Plant	Beaufort Sea	300	1 000	300	1980 - 85	28 x 10 ⁶ m ³ /d
	Norman Wells Expansion	Norman Wells, NWT	2 000			1980 - 85	4 x 10 ⁶ m ³ /d
	Parsons Lake Gas Plant	80 km from Inuvik	400			1983 - 84	8.5 x 10 ⁶ m ³ /d
Gulf Canada	Arctic Islands Gas Dev	Arctic Islands	300			1985 - 90	
Pan Arctic	Niglingak Gas Plant	Mackenzie Delta	10 000			1990 - 96	
Shell Canada Resources	Offshore Oil & Gas Dev	Eastern Arctic	200			1985 - 90	4.2 x 10 ⁶ m ³ /d
Unknown			2 000			1990 - 91	

Table F-53 Province Yukon/NWT
Sector Pipelines

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Footfalls Pipe Lines	Dempster Gas Lateral	Mackenzie Delta to Whitehorse	2 475	6 000	1 10	1983 - 89	34 x 10 ⁶ m ³ /d, hook up to Alaska Gas Pipeline

Table F-54 Province Yukon/NWT
Sector Electric Generation & Transmission

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
NEPC	Five Fingers Hydro	Yukon River	100				1981 - 83	

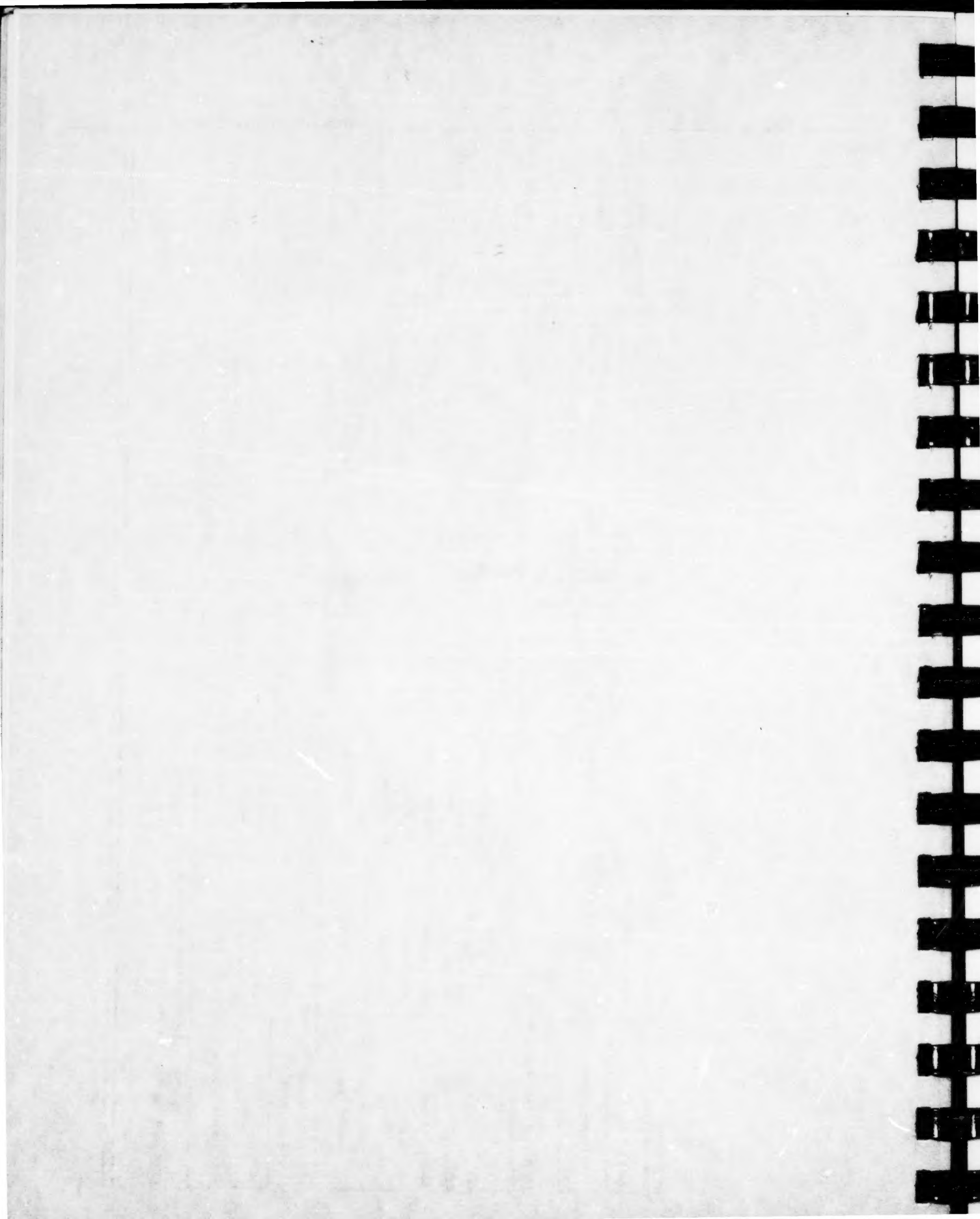
Table F-55 Province Yukon/NWT
Sector Mining

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
Cominco	Atvik Lead, Zinc	Little Cartwells	130				1980 - 82	725 kt/yr.; underway
Cypress Avird	Lead/Zinc/Silver	Faro, Yukon	240				1980 - 81	
International Utilities	Lupin Gold Mine	Conowogio Lake, NWT	115				1980 - 82	320 kt/yr. (ore)
Hudson's Bay Oil & Gas	Lead, Zinc	Town Claims, Yukon	250(e)					
	Lead, Zinc	Howard Pass, Yukon	250(e)					
	Lead, Zinc, Tungsten, Silver	McMillan Pass, Yukon	250(e)					
	Lead, Zinc, Silver, Tungsten	Jason, Yukon	250(e)					

Table F-56 Province Yukon/NWT
Sector Transportation

OWNER/SPONSOR	PROJECT	LOCATION	ESTIMATED CAPITAL COST (\$ MILLIONS)	CONST. MANPOWER PEAK FORCE	MAN YEARS	OPERATING MANPOWER	CONST. PERIOD FROM TO	COMMENTS
NTCL White Pass & Yukon	Barge System Expansion Rail Expansion to Faro	Mackenzie River System Yukon Territory	150(e) 180				1986 - 89	Support to Beaulieu Sea development

APPENDIX G DESCRIPTION OF FORECASTED PROJECTS



CARMONT VENTURE - HEAVY FUEL OIL UPGRADER - (Source: The
Globe & Mail, March 8, 1982, p.R18).

The venture has a good chance of going ahead for completion in 1986, project director Nicholas Gravino said.

Most of the government clearances have been received and upgrading technology has been selected. A final decision may come in June.

The project, sponsored by the Carmont consortium, is designed to convert surplus residual fuel oil into components for higher-value products, mainly transportation fuel. It will

also help reduce imports of foreign crude.

Members of the consortium are Gulf Canada Ltd., Shell Canada Ltd., Texaco Canada Inc. and BP Canada Inc., all of Toronto; Petro-Canada, the federal oil corporation, and Société Québécoise d'Initiatives Pétrolières, the Quebec Government's oil and gas agen-

cy. Their equity commitment is based on the volume of residual oil they will supply to the central upgrader.

The upgrader's proposed capacity has been reduced by half to between 40,000 and 45,000 barrels a day of residual oil, mainly because of the withdrawal of Toronto-based Imperial

Oil Ltd. from the project. Imperial Oil decided instead to do its own upgrading at its Montreal refinery.

The cost of the upgrader is an estimated \$1.2-billion in current dollars, including links to five of the six Montreal refineries it would serve. The upgrader would channel its output to the refineries for final

processing.

The upgrading process, using hydrogen conversion plus delayed coking, was selected in January, and the choice between two U.S. licensors for the technology will be made this month. The site would be on Gulf Canada's refinery property in Montreal.

The project would include a unit to produce high-quality metallurgical coke, used primarily for making electrodes for aluminum smelting.

The second phase of the Carmont feasibility report, costing between \$5-million and \$6-million, is expected to be completed toward the end of May.

The products of the Carmont upgrader will be methane, naphtha and petroleum gases, gas-oil, diesel and jet fuel and coke. Some of these could be used by Petromont Inc. of Montreal as feedstock for its base petrochemical operations.

DEVELOPMENTS IN HEAVY OIL UPGRADING - (Source: Chemistry
In Canada, February, 1982).

The Alberta Oil Sands Technology and Research Authority (AOSTRA) has signed two agreements with companies interested in the evaluation and testing of heavy oil upgrading processes.

AOSTRA and 11 industrial participants entered into an agreement with an estimated value of \$3.5 million to evaluate nine heavy oil upgrading processes. The study was divided into two phases. The first phase of this study is now complete and identifies those processes to be evaluated and terms of reference for the study. Phase II will provide the actual detailed comparative evaluation of the processes.

AOSTRA, Kureha Chemical Industry Co. Ltd., Chiyoda Chemical Engineering and Construction Co. Ltd., and Mitsui and Co. Ltd., signed an agreement to perform a series of pilot plant tests of the Eureka Thermal Cracking Process on Cold Lake and Athabasca bitumens. The Eureka Process, developed by the Kureha Chemical Industry Co. Ltd., is presently used commercially in Japan to upgrade residual oils obtained from the refining of Middle East crude oil. This 12 month project will cost \$337,500 (U.S.). AOSTRA will provide 80% of the funds while Canstar Oil Sands Limited, a potential oil sand operator of a surface-mining project, will contribute 20%.

HUSKY OIL PLAINS UPGRADER - (Source: Project Proposal Submission to the Saskatchewan Government - February, 1982).

Several oil companies have been investigating the feasibility of constructing a heavy oil upgrader in Saskatchewan since the mid '70s. Early in 1981, one of these companies (Husky Oil Operations Ltd. - 25%, Saskatchewan Oil & Gas Corporation - 25%, Gulf Canada Resources Inc. - 20%, Petro-Canada Exploration Inc. - 15%, and Shell Canada Limited - 15%) joined forces in a consortium to carry the project forward.

The project entails construction and operation of a facility capable of upgrading on the order of 6350 m³ (40,000 bbl.) per calendar day of heavy crude. Should heavy oil production activity proceed favourably, including success in Enhanced Oil Recovery (EOR) projects, it is likely that the upgrader capacity would be expanded considerably (perhaps doubled) in the latter half of the 1980s, necessitating a further construction period. The majority of activity associated with expansion would be localized on the existing plant site.

Plant Structure and Function

The description appearing in this section generally reflects a hydrogen addition (hydrocracking) type of process. Since the process to be used in the upgrader has not been finally selected, it is yet possible that a carbon rejection (coking) process could be adopted. The description which follows would still be generally appropriate, except that a coking unit would be added to the process units and coke (a solid black carbon) would be produced as a byproduct.

(a) *Major Components:* The major components that comprise the upgrader complex are typical of those found in refineries. They include distillation columns, reactors, pumps, compressors,

storage tanks and intermediate vessels. All of these components will be linked together via piping and instrumentation to monitor and control the plant's operations. A generalized site layout appears as Figure 3. The ultimate layout of units and facilities will suit the particular characteristics of the chosen site.

(b) *Process:* The primary purpose of the upgrader is to convert heavy oil to a light synthetic crude suitable for use as a feedstock in a conventional refinery. The overall conversion process is accomplished in several stages (see Figure 4). The Consortium is currently concluding process optimization studies to finalize the process selection.

Diluent (condensate), which is used as a transport medium to "thin" the heavy oil before it is put into a pipeline, is separated from the heavy oil in the crude unit in the first step at the upgrader. A balanced volume of diluent is returned to the producing fields, while the excess volume arising as a fraction of the heavy oil itself is routed to the naphtha hydrotreater. The heavy oil is then cracked at a high temperature and pressure in the primary upgrading unit. This yields sour gas (so termed because of the presence of sulphur compounds) and various fractions of the crude. The sour gas is treated to remove the sulphur component, and subsequently used as upgrader fuel. The sulphur produced in the process will be a saleable byproduct.

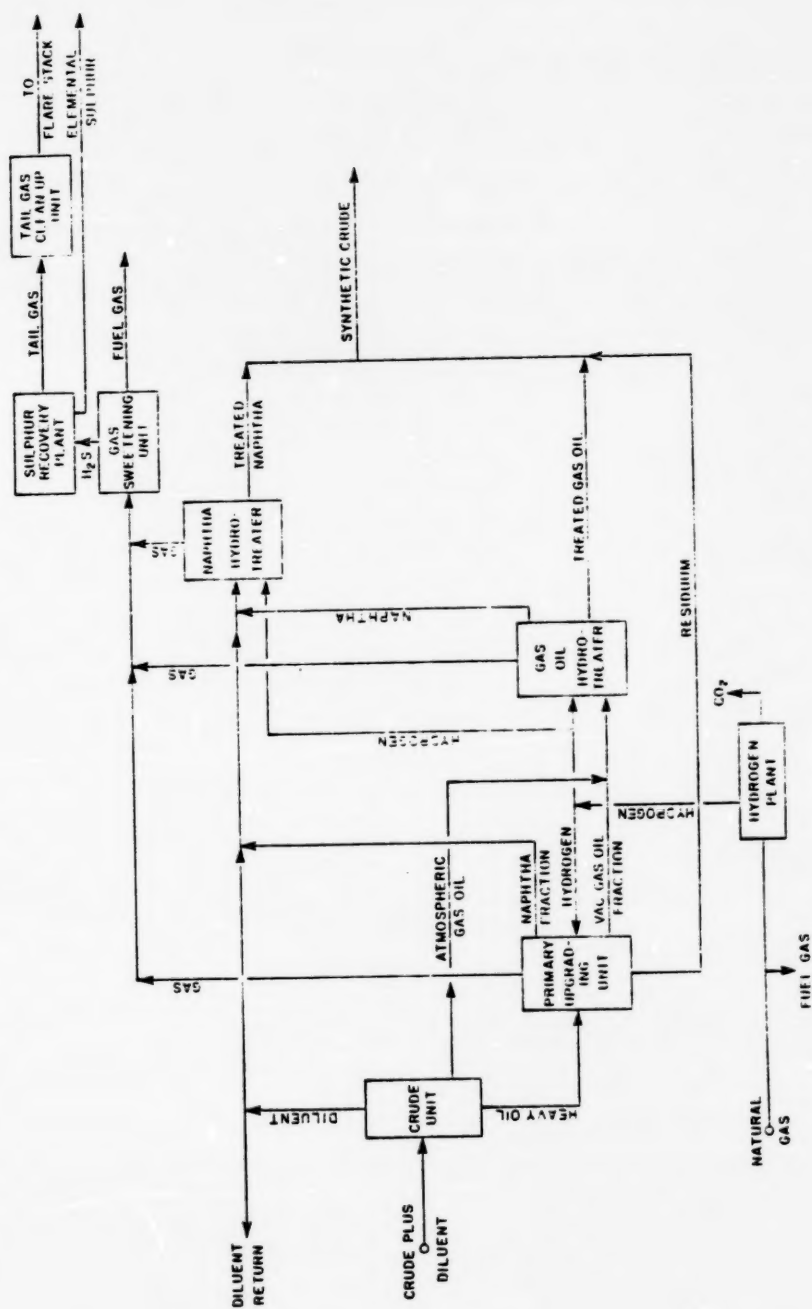
Each of the crude fractions must be treated further with hydrogen in the presence of catalysts in hydrotreaters to remove inert

elements like nitrogen or undesirable substances such as sulphur and aromatics. All of the treated fractions are finally blended to give a synthetic crude suitable for delivery to a refinery.

- (c) *Inputs/Outputs:* The major material inputs to the plant are feedstock (comprised of heavy crude and diluent), natural gas, water and catalyst. The plant design capacity will be on the order of 6350 m³ (40,000 bbl.) per calendar day, with a water requirement of about 7000 to 11,000 m³ (1½ to 2½ million gal.) per day. Varying smaller quantities of other chemicals and lubricating oils will also be used. Electrical power is another necessary input. Primary outputs from the plant will include the synthetic crude product, diluent, sulphur, spent catalyst, waste water and gaseous emissions. Smaller quantities of various solid and liquid wastes will also be produced.

The block flow diagram (Figure 4) tracks the movement of some of the major input and output materials. Most of the materials will move to and from the plant site via pipelines and railcars. Trucks will also be employed to a considerable extent for smaller volume items such as machinery parts, oils, and greases.

Plains Upgrader Project Process Block Flow Diagram



PETRO CANADA PILOT PLANT - (Source: The Globe & Mail,
March 8, 1982, p.R18).

Petrocan, whose studies several years ago led to formation of the consortium, has begun engineering work on an upgrader with a capacity of 5,000 barrels a day at the Petrofina Canada Inc. refinery in Montreal. Petrocan completed the acquisition of Petrofina last year.

This upgrader, costing more than \$100-million, will use the Canmet hydrocracking process developed up to the pilot plant stage by the federal Department of Energy, Mines and Resources in the past decade. The project would remove a small amount of surplus residual oil from the Montreal market.

Petrocan earlier bought the right to commercialize and develop the process further. It hopes to market the technology, which could be used to handle heavy oil such as that produced in Saskatchewan, in other parts of Canada and abroad.

Site preparation for the Canmet plant is scheduled to start this fall, with full-scale construction under way the following spring for startup in mid-1984.

STATUS OF OIL SANDS PROJECTS - (Source: Cameron Synthetic Fuels Report, December, 1981).

STATUS OF SYNFUELS PROJECTS (Underline denotes changes since June 1981)

OIL SANDS

***** COMMERCIAL PROJECTS*****

ALSANDS ENERGY LTD. (Shell Canada Resources, Ltd.) - Shell Explorer, Amoco Canada, Chevron Standard, Dome Petroleum, Hudson's Bay Oil & Gas, Petro-Canada, Gulf Oil Canada

Proposed commercial bituminous sands plant of 137,000 BPD. Located on Lease 13 (Shell) and Leases 12 and 34 (Fina-Daphne) at Athabasca, Alberta. Mining—electric dragline, bucket wheel excavators; extraction—hot water process; upgrading—fluid coking. Alsands intends to manufacture hydrogen initially by natural gas partial oxidation and ultimately by coke gasification. Consortium of nine members consists of: Shell Canada Resources—25 percent, Shell Explorer—20 percent, Amoco Canada Petroleum—10 percent, Chevron Standard—8 percent, Dome Petroleum—4 percent, Hudson's Bay Oil and Gas—8 percent, Petro-Canada—17 percent, Gulf Oil Canada—8 percent. The consortium's application was heard by ERCB in June 1979 and substantially approved in December. A preliminary field program, including site clearing and drainage, was begun, January 1980. An acceptable tax package will still have to be negotiated with the federal and provincial governments.

Project Cost: Estimated at \$13 billion

ESSO RESOURCES CANADA LIMITED - Cold Lake Project

Esso Resources Canada Limited has completed the design of a 141,000 BPD commercial oil sands extraction project near Cold Lake, Alberta. Esso Resources is a wholly owned subsidiary of Imperial Oil Limited, encompassing the latter's upstream assets and operations. The Cold Lake project will recover heavy oil from the reservoirs by in situ steam stimulation with subsequent fluid pumping. About half of the Project investment involves bitumen upgrading facilities. The primary conversion step in the upgrading is the Exxon Research and Engineering Flexicoking process, followed by hydrotreating to reduce sulphur and aromatics content, and to adjust yield patterns. The resulting upgraded crude will be suitable for most Canadian refineries to satisfy product demand slates with existing processing equipment. Esso Resources will act as the plant operator and is inviting financial participation by other interests. The Alberta Energy Resources Conservation Board held extensive public hearings on the Cold Lake Project and submitted a favorable recommendation to the Alberta Provincial Government on October 29, 1979. The final step in the public approval process for the Project is the decision of the Alberta Government. This decision was deferred, pending an agreement between the Federal and Province of Alberta Governments on future Canadian crude price increases and the sharing of the resulting revenues between the two levels of government. While these agreements were being negotiated, the Federal Government advanced \$40,000,000 to Esso Resources to maintain its Cold Lake project team intact, through July 1, 1981, permitting implementation to proceed promptly on receipt of Alberta approval of the project. In July, work on the project was suspended and personnel re-assigned to other projects since all tasks had been accomplished. The next steps would be the commencement of field construction and equipment ordering. Esso felt unable to undertake these major financial commitments in the absence of agreements with the Federal and Alberta Governments to provide a satisfactory return for the project.

On September 1, 1981, the Alberta and Federal Governments signed a new Energy Agreement. The terms of this agreement do not achieve the return target of 20% discounted cash flow. Discussions are being held with the two governments to develop a common understanding of the project economic data as a preparatory step to further negotiations of acceptable terms for the project. Meanwhile, work on the project remains in suspension.

Project Cost: Estimated cost \$12 billion

STATUS OF SYNFUELS PROJECTS (Underline denotes changes since September 1981)

COMMERCIAL PROJECT (Cont.)

CANSTAR — Petro-Canada, Nova — An Alberta Corporation

A fourth oil sands plant is planned on a site in the Athabasca deposit. The plant is expected to produce 100,000 to 150,000 barrels per day at an undisclosed cost. Both Husky Oil Ltd., and the Alberta Indian Tribes have been offered a 10 percent share each in the project. Work has begun on the preparation of a regulatory application at a cost of \$100 million (Cdn). The application is scheduled to be submitted by August 1982, with construction to begin in 1985 contingent upon approval, and plant start-up by 1990.

Project Cost: Estimated total cost \$12 to \$15 billion

SANDALTA-Home Oil Company, Ltd., Alminex, Ltd., Gulf Canada Resources, Inc.

Home Oil Company Limited, in October 1979, announced the farmout of its Athabasca oil sands property to Gulf Canada Resources, Inc. The property, Oil Sands Lease #0980090001 (formerly BSL #30) consists of 15,086 hectares (37,715 acres), situated 43 kilometers (26 miles) north of Fort McMurray on the east side of the Athabasca River. Under terms of the farmout agreement, Gulf, through expenditures totalling some \$42 million, can earn up to an 83.75 percent interest in the lease with Home retaining 10 percent and Alimex Ltd. 6.25 percent. An exploratory drilling program was carried out in the 1980 and 1981 drilling seasons, and evaluation of the results will be continued in 1982. A decision to proceed with commercial development will not be made until 1986.

Project Cost: Gulf Canada Resources, Inc. only \$42 million.

COAL LIQUIDS DEMONSTRATION PLANT

One coal liquids demonstration plant is expected to be built subsequent to the current round of coal liquefaction studies. This will be based on direct liquefaction and will be a small scale plant - $3185 \text{ m}^3/\text{d}$ (20,000 b/d) - suitable for demonstrating the technology in a commercial scale module. Such a plant will accept a feed of about 6500 t/d of coal and would include upgrading and hydrogen production. The plant would provide actual operating experience with indigenous coals and would provide the opportunity to confirm equipment selections and to develop firmer cost estimates for commercial operation.

DIRECT COAL LIQUEFACTION

The liquefaction of coal on a commercial scale is expected to be carried out in one plant in the forecast period, although it is not possible to provide a geographic location. Such a plant is expected to consume about 23,000 t/d of coal and produce approximately 9554 m³/d (60,000 b/d) of liquid hydrocarbon products. The plant will produce the hydrogen required for both liquefaction and upgrading internally, by gasification of either coal or residual liquids and from in-plant generated refinery gases. The plant design will be strongly dependent on the process eventually selected, but will comprise high pressure liquefaction reactors, hot and cold separators and washtowers in the liquefaction section, hydrotreaters, hydrocrackers and separators in the upgrading section and gasifiers and associated shift converters and gas separators in the hydrogen production plant.

INDIRECT COAL LIQUEFACTION

Commercial liquefaction of coal indirectly through gasification and subsequent synthesis of hydrocarbon liquids is expected to be exploited in one plant in the forecast period. Such a plant would likely, in the North American content, be based on entrained gasification at high pressure rather than using the Lurgi gasification route, commercialized in South Africa. Such a plant producing 7962 m³/d (50,000 b/d) of liquid hydrocarbons would consume 40,000 t/d coal. The plant would consist of coal preparation, gasification, gas processing and product upgrading sections. Product upgrading, based on the Sasol experience in South Africa, gives some flexibility in the proportions of gasoline and diesel fuel in the final product mix through the processing of C₃- in polymerization and isomerization units. It is also possible, should the market balance change, that the Mobil developed M-gasoline process would be followed instead of Fischer-Tropsch. The former produces a higher yield of gasoline, but negligible diesel fuel.

CO₂ AND H₂ FOR ENHANCED OIL RECOVERY AND UPGRADING

A plant for jointly producing CO₂ and H₂ from coal will consist of coal preparation and gasification sections followed by a gas processing train involving shift reactors and gas separation. In accord with current trends in technology, a high pressure gasification process is projected with subsequent gas processing also taking place at elevated pressures. The plant will be based on Prairie subbituminous or Foothills bituminous coal and for a production of 4.2×10^6 Nm³/d CO₂ and 5.7×10^6 Nm³/d H₂ would require some 5,000 t/d of coal. Location of such a plant would have to be determined by the economics of the overall scheme considering the rates of demand for the products, storage requirements and transportation options for coal, CO₂ and H₂. The use of CO₂ is established for enhanced recovery of conventional oil and laboratory results for CO₂ application in heavy oil and in-situ bitumen production have been promising. The most likely areas for commercial development are in heavy oil or bitumen recovery zones where the markets for both CO₂ and H₂ are close geographically. The rate of hydrogen production from such a plant would be capable of upgrading 13,000 t/d of heavy oil or bitumen at a use rate of 445 m³/t (2500 ft³/bbl).